STATISTICAL ANALYSIS OF RADIATION DOSE DERIVED FROM INGESTION OF FOODS

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
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Dedicated to
Gwen, Justin and Michelle

The Best Family in the World!

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This analysis undertook the task of designing and implementing a methodology to determine an individual's probabilistic radiation dose from ingestion of foods utilizing Crystal Ball. A dietary intake model was determined by comparing previous existing models. Two principal radionuclides were considered--Lead-210 (Pb-210) and Radium 226 (Ra-226). Samples from three different local grocery stores--Publix, Winn Dixie, and Albertsons--were counted on a gamma spectroscopy system with a GeLi detector. The same food samples were considered as those in the original FIPR database. A statistical analysis, utilizing the Crystal Ball program, was performed on the data to assess the most accurate distribution to use for these data. This allowed a determination of a radiation dose to an individual based on the above information collected.

Based on the analyses performed, radiation dose for grocery store samples was lower for Radium-226 than FIPR debris analyses, 2.7 vs. 5.91 mrem/yr. Lead-210 had a

higher dose in the grocery store sample than the FIPR debris analyses, 21.4 vs. 518 mrem/yr.

The output radiation dose was higher for all evaluations when an accurate estimation of distributions for each value was considered. Radium-226 radiation dose for FIPR and grocery rose to 9.56 and 4.38 mrem/yr. Radiation dose from ingestion of Pb-210 rose to 34.7 and 854 mrem/yr for FIPR and grocery data, respectively.

Lead-210 was higher than initial doses for many reasons: Different peak examined, lower edge of detection limit, and minimum detectable concentration was considered. FIPR did not utilize grocery samples as a control because they calculated radiation dose that appeared unreasonably high.

Consideration of distributions with the initial values allowed reevaluation of radiation does and showed a significant difference to original deterministic values. This work shows the value and importance of considering distributions to ensure that a person's radiation dose is accurately calculated.

Probabilistic dose methodology was proved to be a more accurate and realistic method of radiation dose determination. This type of methodology provides a visual presentation of dose distribution that can be a vital aid in risk methodology.

CHAPTER 1
INTRODUCTION

The purpose of this study was to design and implement a methodology utilizing the Crystal Ball* program to determine a statistical value, a number, and associated fluctuation of an individual's radiation dose based on foods bought from local stores in Gainesville, Florida, and to provide comparison through analysis to a similar previous study.

The most straightforward approach to an individual's radiation dose determination has been to use a deterministic approach. The calculation stated below will provide a committed effective dose equivalent (CEDE) based on ingestion (intake) of a specific radionuclide, a certain concentration in the food and a dose conversion factor (DCF).

$$\text{Intake} * \text{Concentration} * \text{DCF} = \text{CEDE} \qquad \text{(Equation 1-1)}$$

where

Intake = individual dietary intake (g/day or g/yr)

Concentration = amount of radionuclide in for (pCi/g or pCi/kg)

DCF = dose conversion factor--term to convert activity in foods ingested to dose (mrem/pCi).

* Crystal Ball is a statistical analyses program written by Decisioneering as an addition to Microsoft Excel. This provides Monte Carlo sampling of input parameter distribution and trials to determine an output distribution.

CEDE is a dose quantity that describes the long-term dose to an individual from an intake of radioactive material (Shleien, Slaback, & Birky, 1998, pp. 3-5). Depending on what type of dose the individual was trying to calculate, each variable in the calculation had essentially one, and only one, value determined and set down in the guidelines by various agencies. The guidelines were put into recommendations, and these were subsequently, though much later, written into regulatory guidelines. The advent of better computational methods for radiation dose determination due to better computer hardware and software and increased amounts of experimental data is now leading to more accurate determination of the described dose utilizing a probabilistic approach.

The method of a probabilistic approach versus deterministic approach utilizes the information that the variables are each described by a statistical distribution. These statistical distributions are defined by a mean and its associated fluctuations. Figure 1-1 illustrates the methodology and the concept behind this approach. This method provides a more accurate description of the actual range that each variable might have and the probability assigned to it.

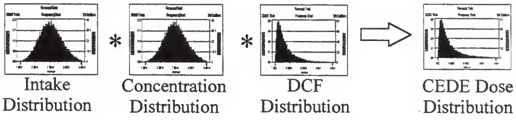


Figure 1-1. Probabilistic Method of Dose Calculation

The Health Physics Society has stated in their most recent position papers that risk assessment must be considered in the context of uncertainties in the estimates (Burk, 2000, p. 232). This statement is in light of the fact that more people and organizations are approaching risk-based policy.

This approach allows determination of a final answer, in this case dose, that also has a distribution. This type of an answer, final dose described by a distribution, provides a more accurate answer by taking into account the distributions of the variables with their associated errors and promulgating them through the equation to come to a final solution.

This document is set up as individual chapters connected by the overall introduction and conclusion. Each chapter has its own introduction and conclusion. Additionally, each chapter describes the previous and following chapters to provide a more unified whole to the reader. The chapters in this document and a brief description of each are organized as follows:

Chapter 1 (Introduction). This chapter provides an overview of the project of both its scope and breadth. The types of approaches to radiation dose evaluation are discussed, both past and present. A brief overview of the different sections of the chapter is discussed.

Chapter 2 (Literature Search). The applicable literature is cited in this chapter. The various studies that have been performed that are specific to the radionuclides, methodology, statistics, and research in this area are reviewed in this chapter. Additional sources are reviewed to determine current work in the area of food radioactivity analysis and diet models utilized to determine dose to an individual.

Chapter 3 (Diet Model). The literary references for the individual diet is provided in this chapter. The methodology for determination of the amended diet is discussed in this chapter. The diet is described for an individual in this portion of the paper. A determination of an individual's intake is made in this chapter as well as the rationale behind the decision.

Chapter 4 (Experimentation). Description of the samples bought, prepared, and counted from three different local stores is considered in this chapter. Concentration data for various foods is determined from the experimental data collected. The distribution of the concentration of radionuclides in food is also undertaken and resolved in this chapter with the analysis of an additional set of samples.

Chapter 5 (Dose Conversion Factors). Explanation of the Environmental Protection Agency's Dose Conversion Factors (DCFs) is provided. The discussion of the various dose conversion factors is considered, and assignment is made to a statistical distribution to the dose conversion factor variable.

Chapter 6 (Committed Effective Dose Equivalent-CEDE). Analysis of the previous chapters with regard to the calculation of the CEDE is considered utilizing Crystal Ball's statistical analysis tools to configure the variables and determine the output. The various methodologies and analyses on both the original 1990 data and the newly measured grocery store data are presented to determine the final dose and the final dose distributions that accompany these data.

Chapter 7 (Results, Conclusions, and Recommendations). The analysis of the final dose determinations and the program to achieve them are presented.

Recommendations for future work are presented, and conclusions based on the output from the above chapters are provided.

Radiation Dose to the Public

An individual is expected to get an average annual dose of 360 mrem (Shleien 1998). Geographic and other factors can change this value from 75 to 5000 mrem. Individuals are constantly exposed to radiation of all types: cosmic, terrestrial, natural internal. Without sunlight life itself would be impossible, but radiation has a bad connotation to the public. People fear the word and the associated images that it conjures up. The public thinks of Three Mile Island and Chernyobl when the issue is discussed, but radiation is all around us and is a vital and important part of our world. The plants are the focus of this paper. This dissertation and chapter seek to determine through theory and experimentation what level of radioactivity is found in our food and provide a statistical analysis for an improved completeness of description.

Hypothesis

The hypothesis of this dissertation is that the ingestion of radioactivity found in of foods bought from local stores should be measured and analyzed to determine its significance. This value that is experimentally measured from foods should have a statistical value that can be described by a distribution. The final dose that is determined from these measured values additionally should have a statistical value with a distribution.

Goals and Objectives

The following provides a list of goals and objectives for this dissertation:

1. Perform a literature search on radioactivity of foods bought in local stores in Gainesville, Florida, as well as previous studies performed on Florida foods or the associated radionuclides.
2. Determine a dietary intake of foods based on previous studies.
3. Measure foods bought from three different local stores and determine radioactivity of lead-210 and radium-226 in these samples.
4. Measure one set of samples to determine distribution to be associated with concentration of radionuclides in food.
5. Determine the distribution to utilize for the EPA's Dose Conversion Factor.
6. Perform Crystal Ball analysis to determine the final dose, in distribution form, to the individual from the original FIPR study data and from the experimentally measured grocery store data.
7. Analyze the results to provide a comparison to the total dose.
8. Compare deterministic and probabilistic methodology of dose calculation.

CHAPTER 2
LITERATURE SEARCH

Introduction

This dissertation covers several fields of study; therefore, a literature search needs to be performed to find the relevant references in each of these areas. The areas of search that are involved in this dissertation are dietary intake, food concentration, radionuclide, dose conversion factors, committed effective dose equivalent, and statistical distributions. This literature search examines the various literature sources that were utilized for each of these categories.

Dietary Intake Data

The dietary intake of an individual is quite often information that is specific to the individual. The dietary intake varies by person due to individuality of the person as well as local customs and availability of food. In an effort to determine dietary intake of an individual in Florida, the first source that was researched included previous studies performed in Florida.

A study of radioactivity in Florida foods and the diet of Floridians necessarily begins with an assessment of study in the field, both past and present. Some of the most recent work in Florida that has examined radioactivity in foods in Florida was performed by the Florida Institute of Phosphate Research (FIPR) (Guidry, Roessler, Bolch, McClave, Hewitt, & Abel, 1990). This organization was created by the Florida Legislature in 1978 to conduct supportive research to the development of the state's

phosphate resources. This organization has done studies in this field due to its interest in the environmental aspect of phosphate mining.

There are three sources that provided information both for the dietary model and the initial concentration of radionuclides in food grown on phosphate and related lands. The first document is the 1986 FIPR report that provided the initial analysis of radium-226, lead-210, and polonium-210 in foods grown on phosphate lands (Guidry, Bolch, Roessler, McClave, & Moon, 1986). The initial diet model that describes dietary intake was first presented in this document. The method of analysis and the dose evaluation were described in this book. Simplified analysis of radionuclide concentration in foods was performed to determine dose to an individual. Three individuals were considered: control, local, and maximum. A control individual was a reference individual who consumes "sampled" foods not from mining-related lands. A local individual consumed 10 percent of his "sampled" foods from phosphate lands and 90 percent from control lands. A maximum individual consumed 100 percent of "sampled" foods in his diet from phosphate (clay) lands. This individual reflects worst case scenario (Guidry et al., 1990, pp. 118-119).

The next two documents were associated with this initial document. Brian Birky's master's thesis referred to the previous document and used the same methodology, diet, and radionuclides to determine dose attributable to technological enhancement of this phosphate reclaimed land (Birky, 1990). This document detailed the previous methods and studies that were utilized to prepare, enclose, and measure the experimental samples. This thesis discussed the methodology utilized to calculate the

dose to an individual directly from the dietary intake spreadsheet. This thesis was much more descriptive in the details of diet and dose calculation than the initial paper.

The 1990 FIPR paper was a continuing study based on the recommendations of the 1986 FIPR paper mentioned above (Guidry et al., 1990). This paper utilized the same basic dietary intake model of the initial study. Some of the same radionuclides were considered. This document focused primarily on three radionuclides and five land types. Three types of individuals were considered in this paper also: local, control, and maximum. The basic dietary model, with few revisions, was presented in this paper. This paper analyzed the differences in the data as well as performing regression analysis on the collected data. This paper had more data points added and more analysis performed that detailed the soil-to-plant transfer model and refined the dietary intake model.

FIPR has continued to improve its database with more samples since this report, and the extended database will be available in a publication in the near future. The current research and work also has continued to smooth the statistical data.

An important point was brought about by direct discussion with Dr. Birky: sampled versus nonsampled diets (B. Birky, personal communication, March 13, 2001). A vital consideration in any analysis is the thought given to what foods were and were not sampled and how to consider them in the final dose determination. These papers and the subsequent meeting provided invaluable insight into this particular point.

These papers primarily discuss the various analyses performed on foods grown on Florida lands in general and phosphate lands in Florida in particular. These were the most useful and pertinent with regard to this analysis.

Concentration of Radionuclides in Food

The concentration of radionuclides in food has been studied in several areas and contexts. The previous three papers discussed this very subject and determined the concentration of several radionuclides in various foods grown on phosphate-related lands.

A study funded by FIPR and performed by the Audubon Society studied the concentration of radium-226 in alligators, armadillos, and soft and hard shell turtles (Pritchard & Bloodwell, 1986). These data relate that the hazard from eating these mammals on mine-impacted lands is unclear.

Dietary intake of lead-210 has been discussed in several articles. Linsalata (1994) discusses human exposures along plant and animal pathways to thorium, uranium, radium, lead, and polonium. The exposure pathways were considered, and the author states that much more work needs to be done in assessing the transfer of lead-210 and polonium-210 in the human food chain.

Morse and Welford (1971) discusses the dietary intake of lead-210 in the diet of New York city residents with a result of 1.2 pCi lead-210 per day. This food diet only included 19 food items. An interesting note is the fact that the concentration of lead-210 was calculated as 0.70 pCi lead-210/kg food.

An analysis was performed on radionuclide contact in Hong Kong food. Yu and Mao (1999) gives an excellent description of the types of gamma spectroscopy system used. The diet model and the results were detailed in tabular form with seven radionuclides under examination. Potassium-40 was found in all solid food and drink

samples. Lead-210 was measured as being greater than half the contribution to the dose from natural radioactivity.

Carvalho (1995) analyzed the Portuguese population for intake of polonium-210 and lead-210. The author primarily examined these two radionuclides and their ingestion rates for the population. This paper supports the postulation of a different diet model for a different population. The point is also made in this paper that cooking the various food prior to eating is not taken into account.

Dose Conversion Factors

The data for the dose conversion factor (DCF) came from four sources. The first source was Federal Regulatory Guide No. 11 (EPA, 1988, pp. 155-179). This document provides the methodology used to calculate the DCFs for inhalation, submersion and ingestion. The tables of the various DCF data for various radionuclides is included in this manual.

The next two articles, International Council on Radiation Protection (ICRP) 68 (ICRP, 1994) and 72 (ICRP, 1996), provide age-dependent DCFs for workers and members of the public from intake of radionuclides. Although they were examined for the purposes of this report, the new DCFs were not utilized for the purposes of consistency.

The fourth reference for these data was a solution manual that calculated a dose conversion factor for strontium-90 (Turner, Bogard, Hunt, & Rhea, 1988). This was utilized as a reference to describe the method to obtain a dose per unit intake factor from the initial data.

Statistical Considerations

Statistics play a major role in the analyses of this study. Information to utilize Crystal Ball comes from the manual provided with the program (Decisioneering, 1996). The manual provides the instruction to utilize the program as well as examples to familiarize the novice with the operation of the various tools built into the software.

These sources provided the nucleus of the reference material researched to obtain the necessary data for the background to perform this research and analysis. The following chapter discusses the diet model and how it was determined. The next chapter discusses the dose conversion factor to determine which dose conversion factor to use and what distribution to assign to this value for an accurate estimate of dose distribution.

CHAPTER 3
DIET MODEL

Introduction

This chapter is a literature search and subsequent analysis of various diet models currently utilized by regulatory agencies and other organizations. The object of this portion of the work is to determine the most accurate diet model for calculating radiation dose to individuals in Florida from their dietary intake.

The choice of a proper diet model is vital to determine dose to an individual from ingestion. Diet model is not as accurate a term as dietary intake model. This distinction may seem small, but it is significant. A diet model refers to the assumed or predicted intake of certain sources of food to individuals. Conversely, a dietary intake model utilizes surveys of the public to ascertain actual food intake. The goal of this chapter is to ascertain, using major and well-established sources, the most accurate and comprehensive source for the dietary intake model for use with our dose evaluation model.

Numerous sources were researched to obtain this goal. The major sources researched were the Pennington Model, Nuclear Regulatory Commission, the United States Department of Agriculture CHFSII 1976-1978 Study, the 1994-1996 NFCS study, RESRAD, and the Environmental Protection Agency. All of these were studied to determine the most suitable diet model for use with a program to determine dose to the individual.

Several factors are considered in an effort to determine the right dietary intake source for our program and dose determination program. The factors that will be considered to decide on the right source for the final dietary intake model will be the following: the date of the publication, the sources of the publication, the comprehensive quality of the data, and the compatibility with the previous FIPR model.

Initial Model

The diet model used to calculate radiation dose in the 1986 and 1990 FIPR studies was the 1983 Pennington dietary intake model (Pennington, 1983). The Pennington diet model was derived from the Food and Drug Administration's Total Diet Study. The most recent revision of this study was based on data from the 1987-88 National Food Consumption Survey (Pennington, 1992). This information was discussed in the 1990 FIPR study dealing with radioactivity of foods grown on phosphate lands (Guidry et al., 1990). The dietary intake model used only the adult male category and regrouped the 201 items in the Pennington diet intake model. Table 3-1 shows the data from that paper.

As can be seen from this table, there are 17 major categories and 43 subcategories. It detailed intake in grams per day. The sources that are being studied need to be examined to determine unit compatibility and possibility of improvement over this initial model.

NRC Nuclear Regulatory Guide 1.109

The first alternate source examined was the Nuclear Regulatory Commission. The mission of the U.S. Nuclear Regulatory Commission (NRC) is to ensure adequate protection of the public health and safety, the common defense and security, and the

Table 3-1: Diet Food Items from Pennington Diet (Guidry et al., 1990)

Source Item	Intake (g/day)
DAIRY	
Milk	280.99
Cheese	22.41
MEAT	
Beef	129.27
Pork	39.54
Other	69
FISH	20.06
EGGS	30.95
CEREAL FOOD	
Corn Grain	5.18
Grain	4.55
Cereals/Bread	174.7
CAULIFLOWER/BROCCOLI	
Cauliflower	0.71
Broccoli	2.8
LEAFY/COLE VEGETABLE	
Cabbage	7.04
Collard Greens	0.45
Lettuce	23.38
Mustard Greens	0.45
Spinach	3.28
Turnip Greens	0.45
Other	0.76
Celery	0.62
LEGUMES	
Green Peas	7.29
Other Beans	25.71
Nuts	4.94
Other	11.28

Source Item	Intake (g/day)
SEEDS/GRAINS	
Blackeyed Peas	5.61
Rice	22.94
Yellow Corn	14.41
TUBERS/ROOTS	
Carrots	2.92
Onion	4.19
Radish	0.32
Turnip	0.42
Potatoes	85.22
Other	1.1
GARDEN FRUIT	
Cucumbers	2.62
Greens Beans	8.8
Green Peppers	1.99
Strawberries	1.23
Tomato	25.18
Watermelon	3.44
Yellow Squash/Zucchini	1.26
Other	6.55
TREE FRUIT	
Citrus	
Orange	85.26
Grapefruit	7.78
Lemon	10.71
Other	60.36
SOUPS	36.82
CONDIMENTS	54.12
DESSERTS	78.3
BEVERAGE	1172.44
WATER	512
TOTAL	3071.8

environment in the use of nuclear materials in the United States (NRC, 2000). This board and its associated bureaucracy accomplish this mission by presiding over the various aspects of reactor operation, siting, and licensing. Numerous programs and regulations are employed to determine the safety and feasibility of siting and operating a plant. NRC Regulatory Guide 1.109, Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I, employs a dietary intake model to determine dose to an individual from ingestion of radionuclides (NRC, 1977). Tables 3-2 and 3-3 list the consumption of various foods such as fruits, vegetables, meat, and milk.

This information is listed for various groups of people: child, teen, and adult. Additionally, each table details the intake for the average individual and the maximum individual. The data in these tables come from ICRP Pub # 23 from 1975 (NRC, 1977) and AER USDA report of 1974 (NRC, 1977). There are only six categories displayed in Table 3-2 and seven categories in Table 3-3. The data are limited when compared to the Pennington dietary intake model. The units are compatible when converted.

Table 3-2: NRC NRG 1.109 Average Individual Intake (NRC, 1977)

Source	**Child**	**Teenage**	**Adult**
Fruits, Veg and Grains (kg/yr)	200	240	190
Milk (L/yr)	170	200	110
Meat and Poultry (kg/yr)	37	59	95
Fish (kg/yr)	2.2	5.2	6.9
Seafood (kg/yr)	0.33	0.75	1
Drinking Water (L/yr)	260	260	360

Table 3-3: NRC NRG 1.109 Maximum Individual Intake (NRC, 1977)

Source	Child	Teenage	Adult
Fruits, Veg and Grains (kg/yr)	520	630	520
Leafy Veg (kg/yr)	26	42	64
Milk (L/yr)	330	400	310
Meat and Poultry (kg/yr)	41	65	110
Fish (kg/yr)	6.9	16	21
Seafood (kg/yr)	1.7	3.8	5
Other Seafood (kg/yr)	1.7	3.8	5
Drinking Water (L/yr)	510	510	730

RESRAD

RESRAD was researched next. This program was designed by the Environmental Assessment Division of Argonne National laboratories. It was approved by the Department of Energy for evaluation of radioactively contaminated sites (ANL, 1989). This code has undergone several benchmarking analyses. The first release of the code was in 1989. It allows either user input of numerous variables or default variables. Table 3-4 shows these data in tabular form. As can be seen from this table, there are only five food groups in this diet.

Table 3-4: RESRAD Dietary Intake Parameters (ANL, 1989)

Source	Default	Units	Min	Max
Fish	5.4	kg/yr	0	1000
Other seafood	0.9	kg/yr	0	100
Fruit, Veg and Grain	160	kg/yr	0	1000
Leafy Vegetable	14	kg/yr	0	100
Meat and Poultry	63	kg/yr	0	300

There are various sources for this chapter. The seafood data come from the EPA recommendation of two reports performed in 1981 and 1982. The data for the fruit, vegetable, and grain come from the EPA 1990 paper which was derived from two earlier documents: Foods Commonly Eaten by Individuals: Amount Per Day and Per Eating Occasion and Food Consumption: Households in the United States, Seasons and Year 1977-1978. Additionally, since the 1990 document did not address grain consumption, these data were taken from the NuReg 1.109 discussed above. For the leafy vegetable consumption rate, the code refers back to NuReg 1.109 and the average individual. The meat and poultry consumption rate is also determined from NuReg 1.109 and the EPA's 1990 paper with comparison to another paper by Gilbert et al. from 1983. This database, like the NRC model, has a limited number of data points. The units are compatible, but due to the data point limitation, it is not considered as feasible for our diet intake model (ANL, 1989).

Environmental Protection Agency

The Environmental Protection Agency (EPA) has numerous documents, as is evidenced by the above discussion of RESRAD information sources. The most applicable of them is The Exposure Factors Handbook (EPA, 1997). This was first published in 1989 with its update published in 1997. This paper has a wealth of information about food consumption by area, age, sex, and various foods; however, this information is far too voluminous to include in this chapter. The key study utilized to perform this analysis was the EPA analysis of 1989-1991 USDA CSFII study (USDA, 1996). It should be noted here that this analysis in the exposure factor handbook also

included mean and standard errors that might be useful in statistical analyses performed as an extension of this work by future researchers.

The EPA's Federal Guidance Report # 13 : Cancer Risk Coefficients for Environmental Exposure to Radionuclides (EPA, 1995) was also researched but was not seriously considered due to the fact that the intake considered is not broken down by food groups, and the units are in kcal/day, units that are not compatible with our comparison. The limited number of data points also make it incompatible with the previous study.

United States Department of Agriculture

The United States Department of Agriculture (USDA) conducts several food consumption surveys at regular intervals. One of these was mentioned as a reference in the EPA Exposure Factors Handbook (EPA, 1997). Numerous articles discuss the various surveys performed by the USDA (Borrud, Enns, & Mickle, 1996) as well as the trends in food and nutrient intake that are derived from them (Enns, Goldman, & Cook, 1997). This last referenced article compares the 1977 NFCS, the 1991 CSFII, and the 1995 CSFII. There are two major USDA food intake survey projects. They are the Nationwide Food Consumption Survey (NFCS) and the Continuing Survey of Food Intake by individuals (CFSII). The NFCS is conducted approximately every 10 years with the most recent performed in 1987-1988. It should be noted here that the original food intake model in the 1990 FIPR report came from the Pennington model. This model was derived from two other studies, one of which was the NFCS study.

The most recent CFSII was conducted in 1994 –1996. Over the course of the three-year study over 16,000 individuals were queried about their dietary intake on two nonconsecutive days. Obviously, this study produced a large amount of data. These data

were separated in much the same way as the EPA data discussed above. This study has more data points than that of the EPA, NRC or RESRAD studies, but it only has essentially 11 major food categories and 15 subcategories. Table 3-5 shows these data for a one-day sampling of male respondents.

Table 3-5: 1994-1996 CFSII Dietary Intake Data

Source Item	**Intake (gm/day)**
Total Grain Products	361
Yeast Breads and Rolls	63
Cereals and Pasta	89
Ready to Eat Cereal	16
Mixtures mainly grain	128
Total Vegetables	242
Dark Green Vegetables	14
Deep Yellow Vegetables	8
Tomatoes	37
Total Fruits	172
Citrus Fruits	65
Bananas	19
Non Citrus juices and nectars	19
Total Mlk and milk products	256
Total fluid milk	178
Whole milk	54
Lowfat milk	85
Skim milk	35
Milk Desserts	33
Cheese	18
Total meat, Poultry and Fish	275
Beef	38
Pork	15
Mixtures mainly meat, poulty and Fish	137
Eggs	23
Legumes	31
Nuts and Seeds	4

The source of these data, although statistically more accurate in that it came straight from a survey of a large number of respondents, should also be suspect for the simple reason that it is a survey. Surveys have their own inaccuracies due to the people questioned and the method of questioning.

Conclusion

The above databases show that there are a limited number of choices for a comprehensive source for our diet model. The most promising beside the original diet model, the Pennington dietary intake model, is the USDA 1994-1996 CFSII database. This has the largest number of food groups compared to the other databases. The units, grams per year, are the same as the initial diet model. The Pennington model source was from the United States Department of Agriculture NCF study. This database comes from the same organization and the database is newer with more respondents surveyed. These reasons provide that the final source for the dose estimate program should be either the original Pennington Model or the diet from the USDA CFSII 1994-1996. A newer version of the Pennington model would be ideal, but foregoing this possibility the author chooses to utilize the existing Pennington model minimally updated with data from the CFSII 1994-1996 survey. These data are shown in Table 3-6. Should a newer more complete version of the Pennington model become available another comparison will be performed to determine the most suitable model.

Table 3-7 shows the various factors considered in a decision matrix to allow determination of a dietary intake model. Five factors were important considerations. The most important factor was the possibility of similar studies being performed. The initial Pennington model had the dose calculation performed in 1990. The date of publication

was the next factor. Two models had more recent publication dates but due to the following three factors were unsuitable.

Table 3-6: Dietary Model Intake

Source Item	Intake (g./day)
DAIRY	
Milk	193
Cheese	18
MEAT	
Beef	37
Pork	15
Other	217
FISH	14
EGGS	24
CEREAL FOOD	
Corn Grain	5.18
Grain	4.55
Cereals/Bread	174.7
CAULIFLOWER/BROCCOLI	
Cauliflower	0.71
Broccoli	2.8
LEAFY/COLE VEGETABLE	
Cabbage	7.04
Collard Greens	0.45
Lettuce	23.38
Mustard Greens	0.45
Spinach	3.28
Turnip Greens	0.45
Other	0.76
Celery	0.62
LEGUMES	
Green Peas	7.29
Other Beans	25.71
Nuts	4.94
Other	11.28

Source Item	Intake (g./day)
SEEDS/GRAINS	
Blackeyed Peas	5.61
Rice	22.94
Yellow Corn	14.41
TUBERS/ROOTS	
Carrots	2.92
Onion	4.19
Radish	0.32
Turnip	0.42
Potatoes	85.22
Other	1.1
GARDEN FRUIT	
Cucumbers	2.62
Greens Beans	8.8
Green Peppers	1.99
Strawberries	1.23
Tomato	25.18
Watermelon	3.44
Yellow Squash/Zucchini	1.26
Other	6.55
TREE FRUIT	
Citrus	
Orange	85.26
Grapefruit	7.78
Lemon	10.71
Other	60.36
SOUPS	36.82
CONDIMENTS	54.12
DESSERTS	78.3
BEVERAGE	1172.44
WATER	512
TOTAL	2997.58

Table 3-7: Decision Matrix Table

Model	Similar Studies	Date of Publication	Source	Quality	Comparability
Pennington 1990	Yes	1990	1987/8	17 and 43	Good
NRC NRG 1.109	No	1977	1974	5 or 7	Fair
RESRAD	No	1989	1977	5	Fair
EPA-EFH	No	1997	1989/91	----	Poor
EPA FRG # 13	No	1995	1974	----	Not

The source of each model was examined as the third factor. The EPA Exposure Factor Handbook had the most recent source with the Pennington model second. Quantity, or number of food categories for overall diet and possibility to analyze them, was considered with Pennington having the most complete diet and most available food categories. Both EPA documents in this category were not applicable due to the large number of categories and dietary items. Comparability was considered as the fifth and lowest priority category. This column relates to the format in which the data are presented and similarity of individual studies. As an example, EPA's FGR #13 is in Kcal per day, which is difficult to compare with grams or kilograms per day. The Pennington had good comparability, whiel NRC 1.109 resrad were listed as fair due to having comparable units without a specified individual such as a 25-year-old male. All of this led the author to a determination of an updated Pennington diet model as the best choice for the dietary intake model.

A dietary intake model choice is made more difficult due to the fact that it is hard, if not impossible, to define a "normal" individual or diet. This is even more complicated when a limited area such as Florida or Gainesville is chosen. The closest similar previous study to determine individual doses in Florida was the Pennington model. Therefore, an updated Pennington model was chosen.

The errors associated with the various diets were not included only the EPA EFH had errors associated with the dietary intake. The analyses performed in the following chapters assign various distributions which include fluctuations, errors, and variability.

The distribution for this factor is assumed to be a lognormal due to the facts that dietary intake is a variable in which the individual has a wide latitude of intake and therefore some will exercise this power. Allowing for this fact, the factor was evaluated as a lognormal distribution as well as a normal (gaussian) distribution.

The next chapter discusses the results derived from the gamma spectroscopy analysis of the local samples bought and analyzed from the various stores in the Gainesville, Florida, area.

CHAPTER 4
EXPERIMENTATION

Introduction

This is the fourth in a series of seven chapters the overall goal of which is to design and implement a methodology utilizing the Crystal Ball program to determine a statistical value, a number, and associated fluctuation of an individual's radiation dose based on foods bought from local stores in Gainesville, Florida, and to provide comparison through analysis to a similar previous study. This dose will be described not by a singular number but will be expressed as a distribution. This distribution will be determined by a series of analyses, on both the 1990 FIPR diet and a new set of data determined by experimentation utilizing the Crystal Ball program to evaluate the distribution and value of the final dose.

Crystal Ball is a forecasting program that is an "add-on" program to Microsoft Excel (Decisioneering, 1996). Initially designed as a financial forecasting program for business analysts, this program has a unique and powerful ability to determine the dose distributions that are under investigation. A Monte Carlo random sampling technique is utilized within the program to determine the distribution of the final outcome.

The goal of this chapter is to describe the analysis performed on various samples to determine the concentration and distribution of radionuclides in the foods purchased. This goal will be accomplished in several stages. Previous work and literature search was undertaken to determine what to measure, how to measure it, and what foods to analyze.

Next, a discussion of the various radionuclides under consideration will be reviewed. Then, the actual experimental analyses will be described. Four separate analyses were performed to measure the concentration of radionuclide concentration in food. The four analyses will be described along with the information obtained. The conclusion will consolidate all the data

Initial Store Samples

Literature Search

The literature search described in the second chapter of this series described the previous samples taken from various locations to assess the radionuclide concentrations in foods grown in several regions around the world. The focus of this chapter was necessarily limited to a study of radionuclide concentration of foods in Florida. The additional sources of literature provided useful comparisons on the various radionuclides considered, the diets studied, and the methods of analyses.

There are three sources that provided information both for the dietary model and the initial concentration of radionuclides in food grown on phosphate and related lands. The first document is the 1986 FIPR report that provided the initial analysis of radium-226, lead-210, and polonium-210 in foods grown on phosphate lands (Guidry et al., 1986). Other radionuclides were also examined in these data. The diet model that describes dietary intake was first presented in this document. The method of analysis and the dose evaluation were described in this book. Simplified analysis of radionuclide concentration in foods was performed to determine dose to an individual. Three types of individuals were considered: control, local, and maximum.

The next two documents were associated with this initial document. Brian Birky's master's thesis referred to the previous document and used the same methodology, diet, and radionuclides to determine dose attributable to technological enhancement of this phosphate-reclaimed land (Birky, 1990). Birky (1990) detailed the previous methods and studies that were utilized to prepare, enclose, and measure the experimental samples.

Additionally, the methodology utilized to calculate the dose to an individual directly from the dietary intake spreadsheet was explained. The explanation was much more descriptive in the details of diet and dose calculation than the initial chapter.

Guidry et al. (1990) conducted a continuing study based on the recommendations of the 1986 FIPR paper. The same basic dietary intake model was used as that considered in Guidry et al. (1986). The same radionuclides were considered. Three radionuclides and five land types were examined. Three types of individuals were considered in this paper also: local, control, and maximum. The basic dietary model, with few revisions, was presented in this paper. The differences in the data were analyzed. Regression analysis was performed on the collected data. More data points were added from the previous study, and more analyses were performed that detailed the soil to plant transfer model and refined the dietary intake model.

FIPR has continued to improve its database with more samples since this report, and the extended database will be available in a publication in the near future. The current research and work also has continued to smooth the statistical data. These chapters primarily discuss the various analyses performed on foods grown on Florida lands in general and phosphate lands in Florida in particular and are the most useful and pertinent to this study.

The concentration of radionuclides in food has been studied in several areas and contexts. The previous three chapters discussed this very subject and determined the concentration of several radionuclides in various foods grown on phosphate-related lands.

To provide for data for this report, and as a means of comparison for the previous report, similar samples were taken from local stores. This chapter will discuss the radionuclide considerations, the stores utilized, the samples taken, the method of measurement, and the results of the measurements.

Radionuclide Considerations

Three radionuclides were considered consistently in the previous reports: lead-210, radium-226, and polonium-210. Each of these is of concern for various reasons. All are from the uranium decay chain, and two are progeny of radium-226. The lead-210 and radium-226 radionuclides will be discussed in turn.

Lead-210 (Pb-210)

This radionuclide is a progeny of radium-226 through decay of radon-222. Lead-210, unlike radon, is a reactive radioisotope that adsorb onto particulates and therefore pose a possible risk to humans through ingestion and inhalation. Most environmental lead is associated with sediments, and the rest is in dissolved form. Short-term exposure to even low levels can cause changes in red blood cell chemistry; developmental problems; and attention span, hearing and hearing and learning disabilities in children. Adult short-term exposure can cause a slight increase in blood pressure. Long-term exposure has been linked to cerebrovascular and kidney disease (Weiner, 2000, pp. 221, 222). Environmental and toxic considerations aside, a large fraction of the lead-210 in the environment have been formed following the decay of radon-222. Therefore, higher

concentrations of lead-210 are found in the surface soils. This increases the chance of intake through the human food chain adding to an individual's dose (Harley, 1988). Additionally, lead was analyzed in the previous FIPR studies and provides a point of comparison for the experimental data obtained in this study.

Radium-226 (Ra-226)

There are more data on this radionuclide than on any other radionuclide. Inhalation of radon daughters account for 55% of the human exposure to natural sources of radiation (Shleien et al., 1998). Radium toxicity is related to bone sarcomas and sinus sarcomas due to its competition for bone with calcium. These factors as well as the fact that the FIPR database includes this radionuclide led to the consideration of radium-226 as one of the points for analysis in this study.

Original versus New Database

There are two databases that could have been considered from the FIPR studies of the previous radionuclides. The original database from the 1990 FIPR report was chosen because the newer database has not been completed, confirmed, or published. The original database considered all three radionuclides and the diet model and has been in the literature numerous years. These reasons led to inclusion and comparison of the original database.

Samples Considered

The March 1986 FIPR report analyzed over 100 food samples, replicated up to three times, collected from 62 land parcels. The Phase 2 1990 FIPR report initial report collected and evaluated approximately 70 samples from five land parcels. These samples

were considered to determine the samples to evaluate from the stores. The samples are listed in Table 4-1.

Table 4-1: Food Samples Analyzed from Local Grocery Stores

Beef	1
Beef Kidney	1
Black-Eyed Peas	3
Brazil Nuts	1
Brazil Nuts Shells	1
Broccoli	3
Cabbage	3
Carrots	3
Cauliflower	3
Collard Greens	3
Corn	3
Cucumber	3
Eggplant	3
Grapefruit	3
Green Beans	3
Greens Onions	3
Green Peppers	3
Irish Creamer Potatoes	1
Lemons	3
Lettuce	3
Lima Beans	3
Mustard Greens	1
Okra	3

Onions	3
Oranges	3
Parsley	3
Peas	3
Pole Beans	2
Potatoes	3
Purple Hull Peas	2
Radishes	3
Red Potatoes	2
Rice	3
Spinach	3
Strawberries	3
Swiss Chard	1
Tangerine	2
Tomatoes	3
Turnip Greens	3
Turnip Roots and Greens	1
Turnip Roots	2
Watermelon	2
Yellow Corn	3
Yellow Squash	3
Zucchini	3
Total	113

The samples taken ranged from beef to zucchini. There were 113 samples total; 45 foods were sampled. A sample is considered as a 0.5 marinela beaker filled with the food in question. Eight foods had only one sample; 6 foods had two samples; and the remainder of the foods, 31, had three samples. This provided a good average for each food from the three stores.

Samples were bought from three stores in the local area to provide a better statistical analysis. Samples were purchased from large supermarkets to increase the

usefulness of this analysis. People outside the Gainesville area and the state of Florida could utilize these same data in other areas of the country. The first set of samples was purchased from Publix at 5200 NW 43rd Street on 12 August 2000. Albertsons at 3930 SW Archer Road was the site where the second set of samples was purchased on 13 October 2000. The third store was Winn Dixie at 7303 NW 4th Boulevard where the third set of samples was purchased on 20 December 2000. It is important to note that some of the samples only had one or two replicates. This was usually due to the limited availability of samples due to their seasonality.

Location of Samples

The samples were purchased from the various stores listed above. The question that should be considered is where they were grown. This is an important factor due to soil contamination, plant uptake, and therefore plant contamination. Samples from each individual store come from numerous samples, which often change daily (Greg Sciullo, personal communication, 30 October 2000). Even if a purchaser asks on the day the food is bought, the store can usually only provide the supplier and region and *not* the location at which the food was grown. This is why it is important to do this and follow-up studies that consider exact sources and their soil radioactivity as well as plant uptake and human consumption availability.

Brazil Nuts

Brazil nuts and Brazil nut shells were actually the first product bought sealed and studied. Of all the samples examined, they had the most number of peaks although not all were identifiable.

Food Preparation

All foods were prepared as for normal human consumption. No foods were cooked, and food was cleaned, cut, and sliced to fill individual containers to maximize weight. The foods were then fit into a 0.5-liter Marinelli beaker. The beaker was capped, sealed, and stored for two weeks to allow ingrowth of radon-222 and its daughter products to equilibrium with its parent radium-226. The sample was then weighed and counted on one of two high-resolution gamma ray spectrometers. The scale that samples were weighed on was a Mettlèr P2000N, Serial No. 394916. Detectors 2 and 4 were used for the analysis. Detector 2 is a Germanium well detector, Serial No. 22P63XC, University Property No. 491044 1100485. Also, a Germanium well detector, Serial No. 12841211302, University Property No. 4910 AA 117706, is the University Property No. for Detector 4. The count time varied from 9 to 24 hours. Most samples were counted for 9.5 hours. Sampled items were counted on only two of four detectors available. This was due to consistency of only using two detectors as well as the limited availability of the other detectors.

Grocery Store Analysis

After gamma counting the samples utilizing detectors 2 and 4 in the Environmental Engineering Sciences laboratory, a peak search was performed. Each spectrum was visually inspected for additional peaks that the library search did not recognize.

Radionuclides Evaluated

The 1990 FIPR study evaluated their samples for three radionuclides. This analysis considered the same three radionuclides because they are from the U-decay

series and have identifiable peaks when counted on a gamma spectroscopy system. These are associated with phosphate mining and are exposed to the surface and therefore may be taken up by plants (Guidry et al., 1986). Radium-226 decays through several short-lived isotopes to radon-222. Radon is a gas that accumulates in structures and can provide a significant contribution to an individual's dose.

Radium-226 (Ra-226)

The radium content was calculated by summing the three peaks at 295.2, 352.0, and 609.4 keV. These peaks are from the Pb-210 and Bi-214 daughters. The results are reported in pCi/gm of material measured (pCi/g)

Lead-210 (Pb-210)

The lead-210 content was calculated utilizing the 10.8 keV peak activity. The results are reported in pCi/gm of material measured (pCi/g).

Potassium-40 (K-40)

The potassium-40 (K-40) radionuclide was measured, and data are available for analysis but are not reported in this chapter due to the fact that they were not analyzed in the FIPR 1986 or 1990 report and therefore have little use in a comparison methodology. It is interesting to note that the 1460keV potassium-40 peak was present and easily identifiable in a majority of the samples.

Correction Factor

A correction factor based on the detector, the radionuclide, and the 4513 standard was calculated. The standard has an activity of 33200 pCi. The correction factor was

determined for radium-226 by combining the counts from the three peaks: lead-214 (295 KeV), lead-214 (352 KeV), and the Bi-214 (609 KeV) and dividing this sum by the time to obtain the rate of the sample in counts per second (cps). The equation for the calibration factor is shown below:

Calibration factor (CF) = 4513 Activity/Measured count rate (Equation 4-1)

The calibration factors were calculated and are shown in Table 4-2.

Table 4-2: Compilation of Calibration Factors

	Pb-210 (PCi/cps)	**Ra-226 (Pci/cps)**
Detector 2	3.40E+05	1670
Detector 4	1.10E+05	1664

Calculation

Once the counts for each sample were analyzed and the blank sample counts were subtracted, the number was multiplied by the correction factor and divided by the weight to obtain the answer in pCi/gram. The calculation is shown below:

Concentration = (Sample (cps)-Background (cps))*CF/Weight (Equation 4-2)

Minimum Detectable Activity

Many of the samples returned values of zero at several of the peaks examined. The minimum detectable activity was calculated at each of these data points and reported as the actual activity. This methodology provides for a conservative dose analysis as well as providing a more complete analysis.

A calculation of minimum detectable concentration (MDC) is calculated by first calculating the limit of detection (LD), as shown below in Equation 4-3.

$$\text{Limit of Detection (LD)} = 2.83 * ((\text{Blank}/(\text{time}))^{1/2} \qquad \text{(Equation 4-3)}$$

The MDC is then calculated using the Equation 4-4.

$$\text{MDC (pCi/gm)} = \text{LD (cps)} * \text{CF (pCi/cps)}/\text{Weight (g)} \qquad \text{(Equation 4-4)}$$

Once these data were calculated, they were reported in the data as the counts.

Output of Analysis

Figure 4-1 shows a sample output from the Gamma Vision Program utilized to count the various samples. An output report similar to this one was produced for each individual sample. A spectrum was also printed out to allow a visual observation and comparison with other samples.

```
Detector #4      ACQ 09-Sep-00 at 9:05:03   RT = 34200.0   LT = 34187.1
           Detector # 4 HPGe End Cap in Green Shield
           Beef 09/09/2000
ROI#   RANGE( keV)    GROSS      NET     CENTROID FWHM FW(1/10) LIBRARY ( keV)       Bq
 1   72.11   79.55     1190      297    71     76.91  0.59    1.35  No close library match.
 2  256.31  261.13      354      -25    34    258.66  0.39    0.71  No close library match.
 3  522.34  526.95      457      221    30    524.76  0.66    2.91  No close library match.
 4  623.75  626.36      145       56    13    624.77  1.22    1.74  No close library match.
 5 1492.05 1497.04      959      768    37   1494.45  2.11    3.73  No close library match.
```

Figure 4-1: Sample Report for Beef

Results and Analysis

Appendix A illustrates, in tabular form, the raw data that provided the dose determination. Peak information was determined from reports similar to Figure 4-1. These were output from the library search performed on each spectrum measured from

each sample. Appendix B contains the Crystal Ball analysis charts for the various analyses performed.

Table 4-3 lists the results for this analysis. As can be observed from these data, cucumbers show the highest lead-210 concentration at 47 pCi/g. Beef was observed to have the lowest lead-210 concentration at 0.076 pCi/g. Potatoes, rice, beef kidney, and watermelon show the lowest radium-226 concentration with 0.002 pCi/g. Parsley had the highest observed concentration at 0.029 pCi/g.

Table 4-3: Gamma Spectroscopy Analysis of Local Grocery Samples

	Averages (pCi/g)	
Item	**Pb-210**	**Ra-226**
Beef	0.076	0.004
Beef Kidney	0.357	0.002
Black-Eyed Peas	0.494	0.003
Brazil Shells	1.021	0.003
Broccoli	0.829	0.005
Cabbage	0.858	0.006
Carrots	0.555	0.004
Cauliflower	1.466	0.005
Collard Greens	1.372	0.006
Corn	0.506	0.006
Cucumber	47.082	0.009
Eggplant	1.425	0.006
Grapefruit	0.096	0.005
Green Beans	3.837	0.007
Green Onions	0.852	0.014
Green Peppers	0.431	0.004
Irish Creamer Potatoes	0.120	0.006
Lemons	0.414	0.005
Lettuce	1.237	0.004
Lima Beans	0.963	0.003
Mustard Greens	1.622	0.017
Okra	1.072	0.003
Onions	0.599	0.004
Oranges	0.682	0.003
Parsley	7.378	0.029
Peas	0.821	0.003
Pole Beans	0.704	0.004
Potatoes	0.846	0.002
Purple Hull Peas	0.454	0.003
Radishes	0.580	0.004
Red Potatoes	0.215	0.003
Rice	0.654	0.002
Spinach	0.422	0.020
Strawberries	0.715	0.004
Swiss Chard	2.010	0.006
Tangerine	0.686	0.004
Tomatoes	1.011	0.003
Turnip Greens	0.941	0.006
Turnip Root and Green	1.841	0.005
Turnip Roots	0.941	0.006
Watermelon	0.776	0.002
Yellow Corn	0.680	0.005
Yellow Squash	0.613	0.004
Zucchini	0.108	0.005
Brazil Nuts	1.324	0.007

The average for lead-210 for all samples is 2.037 pCi/g. This value is higher than most due to the largest value increasing the value. All of the samples have concentrations below this value with the exception of parsley and cucumber. The average for Ra-226 is 0.006 pCi/g. Fifteen sample concentrations lie on or above this value with all others measured below. Brazil nuts and their shells cause this value to be higher than most of the measured values. The concentration of mustard greens lies at this value, and all other concentrations lie below this value.

Rice Experimental Analysis

Determination of the distribution associated with the concentration of radionuclides in food was undertaken with the following results. The distribution of a radionuclide concentration in a food was approached utilizing two major methods: experimentally and with a review of relevant literature current studies.

Review of Literature and Current Studies

The 1986 FIPR report initially assumed a lognormal distribution. The subsequent pilot study and analyses utilizing a residual test bore out this hypothesis. This was performed primarily for radium-226 in the various food items for the study. The study analyzed 31 food items in six general categories.

The subsequent 1990 study and the current research agree with the initial analysis from the 1986 paper. The findings were for a lognormal distribution, which was determined by analyses of the data distribution for specific food items grown on each land analyzed for each radionuclide.

Experimental Analysis

Even though these data seem conclusive in one method to assume a lognormal distribution, they do not address the point of different food items, especially the grocery items. This chapter deals with research performed on grocery store items, whereas the previous studies did not. The 1990 FIPR report (Guidry et al., 1990) analyzed one sample of each food type but could not perform any relevant or applicable analyses on only that one data point. This chapter dealt with 3 data points (in most cases) from each food type.

An analysis was undertaken to analyze a food type for the distribution. The results obtained, although numerical in nature, were essentially qualitative. The determination of distribution was obtained through measurement and analysis of rice obtained from Publix and measured for a single radionuclide.

Choice of Food Sample

The rice was purchased from Publix on 4 February 2001. The brand chosen was Publix' own brand. This was chosen both for the price consideration as well as the probability of consumption due to the limited cost by an average consumer. Rice was chosen also because it provided a consistently high potassium-40 peak on prior analyses. This provided a good indication that this sample would provide a good consistent peak to analyze on all samples measured.

Preparation

Similar to all the experimental analysis for this research, the 20 samples of rice were placed in Marinelli beakers. Each 0.5 beaker was filled with rice, sealed and refrigerated for two weeks to allow for ingrowths of the Radon daughters to equilibrium.

Measurement

The samples were weighed after the two-week period. Each sample was then measured on one of two high purity GeLi detectors. Detectors 2 and 4 were chosen for this analysis due to their previous utilization with other samples as well as their availability. The samples were each measured for 9-1/2 hours. Once again, this time was chosen to provide an opportunity for future comparison with other data obtained in this research.

Comparison

The spectrums of the samples, once counted, were individually examined to ensure the potassium-40 peak was observed and analyzed. As expected, the peak was found on every sample to varying degrees. An analysis of the data was performed on the 10 samples measured on each detector as well as overall for all 20 samples.

Results

These data were analyzed for several statistical attributes, such as skewness, maximum, minimum, kurtosis, range, and standard deviation. Tables 4-4, 4-5, and 4-6 show the summary statistics for detector 2 and detector 4. A comparison of the raw data and these numbers illustrate that one point on detector 4 was an outlier. Tables 4-7 and 4-8 show the same statistical comparisons for the combined data with and without the outlier, respectively.

A survey of the statistics from detector 2 (Table 4-4) shows that the range of counts per second per gram for the samples measured was $3.36 * 10^{-6}$. The mean of all samples on these detectors was $5.83 * 10^{-6}$. The standard deviation was $1 * 10^{-6}$. The

skewness, a measure of the distribution to deviate from a standard distribution, is 0.378. This supports the contention of the literature cited above that states that the distribution of radionuclide concentration of food is lognormal, in this case positively skewed.

Table 4-4: Summary of Rice Sample Statistics from Detector 2

SUMMARY STATISTICS DETECTOR 2	
Mean	5.82591E-06
Standard Error	3.18389E-07
Median	5.71661E-06
Standard Deviation	1.00684E-06
Sample Variance	1.01372E-12
Kurtosis	-0.165870891
Skewness	0.378137914
Range	3.36092E-06
Minimum	4.26156E-06
Maximum	7.62247E-06
Sum	5.82591E-05
Count	10
Largest (1)	7.62247E-06
Smallest (1)	4.26156E-06
Confidence Level (95.0%)	7.20248E-07

Table 4-5 shows similar statistics for the samples measured on detector 4. The outlier is included in this analysis for the sake of comparison and to illustrate the effect that the outlier has on the analysis. The mean of the data with the outlier is $5.05*10^{-6}$. The standard deviation is $1.6 *10^{-6}$. The range is $5.96*10^{-6}$. This number is close to twice as large as the range associated with detector two samples. The mean was measured as $5.05*10^{-6}$ and the skewness as $-1.25*10^{-6}$. This is not only larger but in the opposite

direction to the distributions both researched and assumed. An observation of the raw data illustrated that one data point, $1.3*10^{-6}$ was an outlier. Once this was removed, Table 4-6 was obtained and analyzed.

Table 4-5: Summary of Rice Sample Statistics from Detector 4

SUMMARY STATISTICS OF RICE SAMPLES ON DETECTOR 4	
Mean	5.05372E-06
Standard Error	5.16785E-07
Median	5.21956E-06
Standard Deviation	1.63422E-06
Sample Variance	2.67067E-12
Kurtosis	2.670178378
Skewness	-1.254131791
Range	5.96386E-06
Minimum	1.29724E-06
Maximum	7.2611E-06
Sum	5.05372E-05
Count	10
Largest (1)	7.2611E-06
Smallest (1)	1.29724E-06
Confidence Level (95.0%)	1.16905E-06

Table 4-6 illustrates that with the outlier removed, the mean is now higher at $5.5*10^{-6}$. The standard deviation has now been reduced to $1.02*10^{-6}$. The range is now $3.25 *10^{-6}$, less than detector 2. The skewness measured a +0.37, which is very close to that measured for detector 2. These data, with the outlier removed, tend toward a lognormal distribution due to the skewness measured and the similarity of data obtained from both sets of samples.

Table 4-6: Summary of Rice Sample Statistics without Outlier from Detector 4

SUMMARY STATISTICS ON DET 4 WITHOUT OUTLIER	
Mean	5.47111E-06
Standard Error	3.40689E-07
Median	5.52044E-06
Standard Deviation	1.02207E-06
Sample Variance	1.04462E-12
Kurtosis	-0.449095314
Skewness	0.37326003
Range	3.25132E-06
Minimum	4.00978E-06
Maximum	7.2611E-06
Sum	4.924E-05
Count	9
Largest (1)	7.2611E-06
Smallest (1)	4.00978E-06
Confidence Level (95.0%)	7.85631E-07

An analysis was undertaken to compare the same statistics on both data sets combined. There were two analyses performed, one with the outlier and one without the outlier. These are shown in Table 4-7 and 4-8.

Table 4-7 illustrates the summary statistics on the rice samples measured from both detectors combined. Consideration of the outlier would provide a mean of $5.4*10^{-6}$. A standard deviation would be obtained that would be $1.38*10^{-6}$. The range would be $6.3*10^{-6}$ with the minimum and maximum measured at $1.3*10^{-6}$ and $7.6*10^{-6}$, respectively. The skewness would be a $-1.2*10^{-6}$. All of this, as well as the data from detector 4 above, details a reasonable justification for removing the outlier and considering the other 19 data points as the total sample.

Table 4-7: Summary of Rice Sample Statistics: Total Rice Samples

STATISTICS--ALL DATA POINTS	
Mean	5.43981E-06
Standard Error	3.08395E-07
Median	5.49973E-06
Standard Deviation	1.37918E-06
Sample Variance	1.90215E-12
Kurtosis	3.328489995
Skewness	-1.201595498
Range	6.32524E-06
Minimum	1.29724E-06
Maximum	7.62247E-06
Sum	0.000108796
Count	20
Largest (1)	7.62247E-06
Smallest (1)	1.29724E-06
Confidence Level (95.0%)	6.45478E-07

Utilizing the other 19 data points and performing a summary analysis, Table 4-8 is obtained. As can be observed from Table 4-8, similar to the observations from Table 4-6, the mean has now increased to $5.7*10^{-6}$. The standard deviation has now decreased to $1.0*10^{-6}$. The range, $3.6*10^{-6}$ is essentially half of that obtained with the outlier in Table 4-7, and the skewness was increased to a positive $0.32*10^{-6}$, once again supporting the data obtained by the two sources in the literature search from analyses of previous data.

Histogram Analysis

A histogram analysis was performed on the various sets of data prior to the summary statistics that were derived above. These initial analyses were performed to provide a visual representation of the data and their subsequent distributions. They have been included here to provide for a more complete data analysis as well as to show how the outlier was initially found. Figure 4-2 shows the data plotted in a histogram. The

outlier lies to the left-hand side of the plot, conspicuously alone. Further consideration required determination of which detector and sample this number was obtained.

Table 4-8: Summary of Rice Sample Statistics: Total Rice Samples without Outlier

COMBINED STATS EXCLUDING OUTLIER	
Mean	5.65784E-06
Standard Error	2.29904E-07
Median	5.52044E-06
Standard Deviation	1.00213E-06
Sample Variance	1.00426E-12
Kurtosis	-0.512673412
Skewness	0.318703287
Range	3.61269E-06
Minimum	4.00978E-06
Maximum	7.62247E-06
Sum	0.000107499
Count	19
Largest (1)	7.62247E-06
Smallest (1)	4.00978E-06
Confidence Level (95.0%)	4.83011E-07

Figures 4-3 and 4-4 show Detector 2 and 4 rice sample histograms, respectively. Figure 4-3 shows all data in a close grouping and range, whereas the histogram of detector 4 has a similar grouping with the notable exception of one data point.

The detector 4 histogram has a larger range than that presented on the histogram of detector 2. The grouping of detector 2 has a much smaller range when the outlier is excluded. This was the first indication that there was a point that should be removed in the consideration of the data. Removing this data point and replotting detector 4 rice samples in a histogram reveals Figure 4-5.

This histogram reveals the reduced range similar to that obtained with the samples from detector 2. The grouping could be lognormal or normal. A histogram of all samples as well as a statistical summary analyses performed above is a more accurate indicator of distribution. Figure 4-6 shows the histogram of the entire data set with the exception of the outlier.

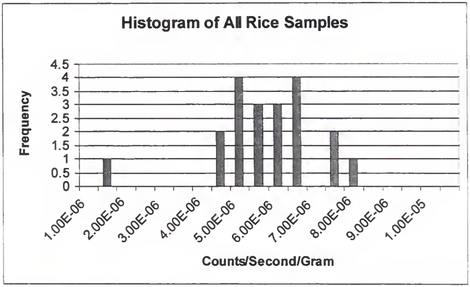


Figure 4-2: Histogram of All Rice Samples

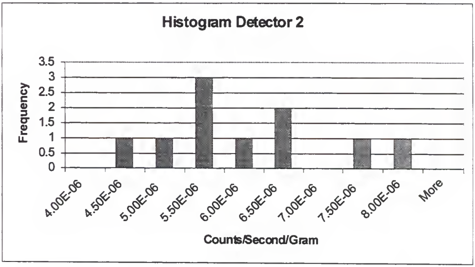


Figure 4-3: Histogram of Detector 2 Samples

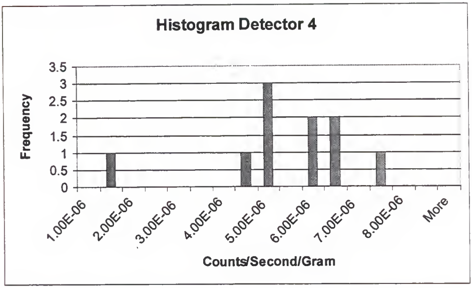


Figure 4-4: Histogram of Detector 4 Samples

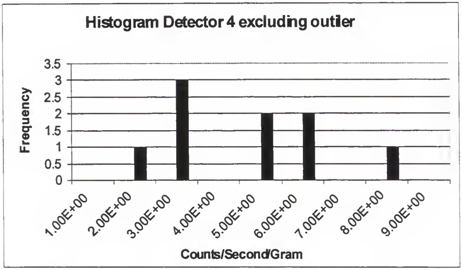


Figure 4-5: Histogram of Rice Samples on Detector 4 excluding Outlier.

This curve illustrates a bimodal distribution around $6*10^{-6}$ counts/gram/sec and has a slightly lognormal appearance. The distribution at this point was determined using the summary statistical analysis to ensure that the outlier removal was justified and to

determine the shape of the distribution. Additionally, the data were analyzed using the Crystal Ball program to determine that the distribution, though limited in number of data points, most closely approximates a lognormal distribution.

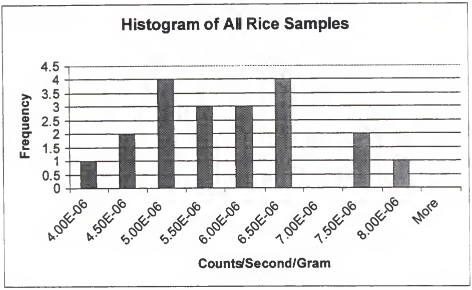


Figure 4-6: Histogram of All Samples excluding Outlier

Conclusion and Recommendations for Future Research

Analyses were performed on 20 rice samples obtained from Publix Supermarket in Gainesville, Florida. The 20 samples were tested on detector 2 and detector 4 of the gamma spectroscopy laboratory at the environmental Engineering Sciences Department at the University of Florida. The goal of this portion of the research was to determine qualitatively what type of distribution is exhibited by concentration of radionuclides in foods. A literature search was performed providing information specific to foods grown on phosphate related lands. These data stated that the distribution followed a lognormal distribution. The analyses on these samples, with histograms and summary statistics, proved that one of the data points was an outlier and, when excluded, provided good

agreement with the data obtained from the previous research. The concentration of radionuclide in food studied in this set of analyses followed a lognormal distribution.

Further research should be undertaken, both in the form of a literature search and experimentally, to determine if this is accurate for a wider range of foods. Studies should be performed to determine how the distribution changes by store, location, and land type. Additionally, the data presented here should also be examined utilizing the residuals method to confirm, with another method, how the data best fit this distribution. Another analysis, with more data points, should be undertaken to determine the distribution with better accuracy.

The above experimental data on grocery store foods was determined utilizing previous studies as a template as well as a guideline to choose which samples to measure. Brazil nuts, although not in the original work, prove to be hyper accumulators. They exhibit the highest number of peaks of any measured food. Their shells also exhibit the same properties. Beef and beef kidney are only one data point and will not be used for the analysis to follow. An interesting point to note about beef is that it illustrates a low lead-210 concentration whereas the kidney shows a high lead-210 concentration. The data examined as a whole illustrate that the concentration of radium-226 is lower, on average, than lead-210.

This chapter has laid down the concentration and associated distributions of various radionuclides in specific grocery store foods. The previous chapter determined dietary intake and the distribution that it is estimated to follow. The next in this series of chapters deals with the dose conversion factor. The data from these three chapters will be

combined in the sixth chapter on dose to provide a more accurate estimate both in number and shape of distribution than currently available in the literature.

CHAPTER 5
DOSE CONVERSION FACTORS

Introduction

This is the fifth in a series of chapters designed to design and implement a methodology to determine a probabilistic radiation dose to individuals from foods bought at local stores in Gainesville, Florida, using the Crystal Ball program. The first chapter provided the introduction of a probabilistic dose approach. The second chapter described the literature search for the overall dissertation to determine the references that were used for each section. The third chapter determined the dietary intake values to be used and the most probable distribution to describe them. The fourth chapter described the actual experimentation performed to determine both the concentration of specific radionuclides in the various foods measured and the distribution to describe this concentration. The purpose of this chapter is to determine the value and distribution to describe the dose conversion factor.

Literature Search

A literature search was performed to determine the various applicable references in an effort to determine the correct dose conversion factor (DCF) as well as a distribution to apply to it. The data for the dose conversion factor (DCF) came from four sources. The first source was Federal Regulatory Guide number 11 (EPA, 1988). This document provides the methodology used to calculate the DCFs for inhalation,

submersion, and ingestion. The tables of the various DCF data for various radionuclides are included in this manual.

The articles International Council on Radiation Protection (ICRP) 68 (ICRP, 1994) and 72 (ICRP, 1996) provide age-dependent DCFs for workers and members of the public from intake of radionuclides.

The fourth reference for these data was a solution manual that calculated a dose conversion factor for strontium 90 (Turner, Bogard, Hunt, & Rhea, 1988, pp. 96-101). This was utilized as a reference to describe the method to obtain a dose per unit intake factor from the initial data.

It should be noted that an additional vital source of information describing the distribution was a direct conversation with Dr. Eckerman at Oak Ridge National Laboratories. He provided the data that stated that the dose conversion factors follow a lognormal distribution. Lead-210 and radium-226 distribution encompass 90% of the values by multiplying and dividing the mean by a factor of five. Polonium-210 distribution can encompass 90% of the values by multiplication and division of the mean by a factor of 10. These data were incorporated into the final analysis of each dose analysis as the ninth case.

Discussion

There are two points which need to be addressed at this point: the distribution and the method to obtain or make an educated estimate and the different sources of DCFs. Either a distribution can be assumed or it can be calculated utilizing the Crystal Ball analysis to assign distributions to each of the variables in the equation. Either approach will produce a final output that will be utilized in the next chapter to calculate

and derive a distribution for the end product dose. The purpose of this chapter is to derive a probabilistic methodology that can predict a distribution for dose.

There are at least three different sources of dose per unit intake or dose conversion factors: the EPA Federal Regulatory guide (FRG) number 11, International Council on Radiation Protection (ICRP) Publication 68 and ICRP 72. These sources and their DCFs are listed in Table 5-1.

Table 5-1: Dose conversion Factors from Various Sources (Sv/Bq)

	ICRP 68	ICRP 72	FRG 11
Pb-210	6.80e-7	6.90e-7	1.450e-6
Ra-226	2.80e-7	2.80e-7	3.58e-7
Po-210	2.40e-7	1.20e-6	5.14e-7

As can be seen from this table, the numbers are not identical and have a rather large variance. The dose conversion factors from Federal Regulatory Guide Number 11 were utilized in this report. These data were chosen to maintain consistency with previous reports and to provide comparability with data from those same reports.

Conclusion and Recommendations

The above data for the EPA FRG number 11 will be utilized for the purpose of this report with the distribution to be assigned as a lognormal distribution. The EPA FRG 11 dose conversion factors will be converted to mrem/pCi to maintain consistency and units.

A suggestion for future work is twofold. The discrepancies between the various agencies and their dose per unit intake should be considered and evaluated. Additionally, the distribution for this factor should be evaluated utilizing Crystal Ball

and the individual factors in the equation to obtain a more accurate determination of the distribution for this factor.

The next chapter combines all the previous data and distributions together. The original 1990 FIPR (Guidry et al., 1990) study is analyzed for a series of distributions for each of the parameters. Two radionuclides are considered: radium-226 and lead-210. The resulting Crystal Ball dose distributions are presented in tabular format. A similar analysis is performed on the grocery store data for each radionuclide. The last chapter sums all the previous data into a combined whole for comparison and discussion.

CHAPTER 6
COMMITTED EFFECTIVE DOSE EQUIVALENT

Introduction

This chapter designed to determine and test a methodology to calculate a probabilistic radiation dose to individuals from foods bought at local stores in Gainesville, Florida. The first chapter provided the introduction of a probabilistic dose approach. The second chapter described the literature search for the overall dissertation to determine the references that were used for each section. The third chapter determined the dietary intake values to be used and the most probable distribution to describe them. The fourth chapter described the actual experimentation performed to determine both the concentration of specific radionuclides in the various foods measured and the distribution to describe this concentration. The fifth chapter described the methodology to determine the dose conversion factor (DCF) value and distribution. The purpose of this chapter is to determine the value and distribution to describe the dose to an individual based on the values obtained in the previous chapters.

This purpose will be accomplished by a literature search that describes the applicable and relevant literature to determine the committed effective dose equivalent, the term to describe the extended dose to an individual based on intake of a specific radionuclide. The data previously obtained were then analyzed with the original data and comparison is provided.

Literature Search

Dose to an individual can be calculated in several ways. The EPA Federal Regulatory Guide Number 11 provides the dose conversion factors utilized in this chapter (EPA, 1988). Other dose conversion factors from ICRP 68 (ICRP, 1994) and ICRP 72 (ICRP, 1996) were considered but not utilized for this analysis. This was to maintain consistency from the previous 1990 Florida Institute of Phosphate Research (FIPR) report. These tables allow the user to calculate a dose to an individual based on the individual's unit intake of a radionuclide.

The 1990 FIPR report was utilized for its diet model and dose analysis of radium-226 and lead-210 (Guidry et al., 1990). The dose analysis from this report was utilized to determine the associate dose and distribution to a known and published value for a diet of an individual living in Florida. The dose model considered from this paper was only the debris land model for each radionuclide owing to the fact that the maximum individual in this category had the highest dose.

Method

Determination of dose to an individual is accomplished by integrating the information determined in the previous papers, multiplying the appropriate factors, summing, and then running Crystal Ball on the entire set to determine an output. Equation 1-1 illustrates the formula to calculate dose to an individual. Each variable in this formula is assigned a value in a Microsoft Excel spreadsheet. The various values for intake, concentration, and dose conversion factors are assigned a distribution from the Crystal Ball library. Crystal Ball, produced by Decisioneering, is a program addition to Microsoft Excel (Decisioneering, 1996). This program utilizes a Monte Carlo sampling

technique for each assigned distribution to determine a final dose in the form of a distribution.

Monte Carlo is a method in which a random sample is picked from each distribution and used in the calculation. Each random sampling, with its resultant output, is called a trial. Depending on the number of trials specified, an output distribution is framed. The more trials performed, the more accurate the distribution.

Specific fluctuations in the variables such as location of individuals, eating habits, land type, where food is grown, radiation type and food preparation methods are taken into account by the distribution determination in each variable. Specific errors are considered as a whole to contribute to the shape of the distribution. A family of distributions and analyses are performed to ensure flexibility of the resultant output in determination of a final dose. Should one specific set not be correct in its distribution choice, other sets will allow the correct determination of dose and associated distribution.

Nine sets of analyses were performed on each radionuclide, lead-210, and radium-226. These analyses were performed on the original 1990 FIPR report and the experimentally obtained grocery store data. The data are presented in tabular format, comparing the different distributions uses and the different distributions obtained for each set. The sets of data are presented below in Table 6-1.

The various sets each have different values for intake, concentration, and dose conversion factors. LN represents a lognormal distribution, and G represents a gaussian distribution. The intake values for each variable were obtained from the previous chapters. The intake values were obtained from the 1990 FIPR report and the third report

in this series. The concentration data were taken from the fourth chapter, the experimental analyses on the grocery store samples and from the 1990 FIPR report. The dose conversion factors were obtained from Federal Regulatory Guide # 11. Default values were utilized for the various parameters that could not be identified. Set nine is a special case that is similar to set 1 with the exception that the dose conversion factor is specified by a more exact representation of the actual DCF. Set 9 is the most plausible scenario for the dose value and distribution. All Crystal Ball analyses were run with 20,000 trials to improve consistency, accuracy, and comparability.

Table 6-1: Sets of Distributions Utilized in Analyses on Data

	Intake	Concentration	DCF
Set 1	LN	LN	LN
Set 2	G	LN	LN
Set 3	G	G	LN
Set 4	G	G	G
Set 5	LN	G	G
Set 6	LN	LN	G
Set 7	LN	G	LN
Set 8	G	LN	G
Set 9	LN	LN	LN

Analysis of 1990 FIPR Dose Diet

Radium 226 Analysis on 1990 FIPR Data

The dose worksheet provided in Table 6-2 shows the spreadsheet for the radium-226 dose calculation that was used as input to the Crystal Ball program. Each of the intake variables and concentration variables were assigned a distribution. The dose

Table 6-2: Input Spreadsheet Data for Radium 226 Dose Calculation (Guidry et al., 1990)

	DCF	1.30E-03	(mrem/pCi)
Diet Item	**Intake (g/day)**	**Concentration (pCi/kg)**	**Intake (pCi/yr)**
Broccoli	3.51	34.67	44.42
LEAFY			
Cabbage	7.04	32.2	82.74
Collard Greens	0.45	86.23	14.16
Lettuce	23.38	45.41	387.52
Mustard Greens	0.45	64.22	10.55
Spinach	3.28	540.25	646.79
Turnip Greens	0.45	55.47	9.11
SEEDS/GRAINS			
Blackeyed Peas	5.61	25.6	52.42
Rice	22.94	82.18	688.10
Yellow Corn	14.41	25.6	134.65
ROOTS			
Carrot	2.92	113.83	121.32
Onion	4.19	33.3	50.93
Radish	0.32	33.3	3.89
Turnip	0.42	23.64	3.62
GENERAL			
Cucumber	2.62	18.6	17.79
Green Beans	8.8	9.79	31.45
Green Peppers	1.99	18.6	13.51
Strawberries	1.23	806.68	362.16
Tomato	25.18	18.6	170.95
Watermelon	3.44	18.6	23.35
Squash/Zucchini	1.26	5.15	2.37
Totals	133.89		2871.78
Total Diet	3071.81		

Dose

Non-Sampled	2.18E+00 mrem/yr
Sampled	3.73E+00 mrem/yr
Total	5.92E+00 mrem/yr

conversion factor was also assigned a distribution. The product of these three variables and a conversion factor allowed the determination of a dose and a distribution.

Table 6-3 shows the output of the family of analyses obtained when the various distributions were placed into the appropriate variables. Table 6-4 illustrates the statistical data to allow for a comparison of the various distributions.

Figure 6-1 is the output of the Crystal Ball forecast for set 9. Figure 6-2 shows the difference comparison between the best fit distribution and the Monte Carlo Crystal Ball determination of the distribution. The scale on the y-axes illustrates that there was close agreement.

Table 6-3: Table of Input and Output Distributions for Radium-226

	Intake	Concentration	DCF	Dose
Set 1	LN	LN	LN	LN
Set 2	G	LN	LN	LN
Set 3	G	G	LN	LN
Set 4	G	G	G	G
Set 5	LN	G	G	Beta
Set 6	LN	LN	G	Beta
Set 7	LN	G	LN	LN
Set 8	G	LN	G	Beta
Set 9	LN	LN	LN	LN

Table 6-4: Statistical Comparison of Various Data for Radium-226

	Mean	Std Dev	Skewness	Kurtosis	COF	Range Width
Set 1	5.91	0.623	0.3	3.17	0.11	4.81
Set 2	5.92	0.625	0.32	3.13	0.11	5.16
Set 3	5.92	0.632	0.3	3.15	0.11	5.1
Set 4	5.92	0.629	0.06	3.04	0.11	4.91
Set 5	5.92	0.627	0.05	3.04	0.11	5.12
Set 6	5.92	0.626	0.05	2.97	0.11	4.62
Set 7	5.91	0.624	0.32	3.3	0.11	6.23
Set 8	5.92	0.624	0.08	3.04	0.11	5.28
Set 9	9.56	12.1	5.08	53.59	1.26	270

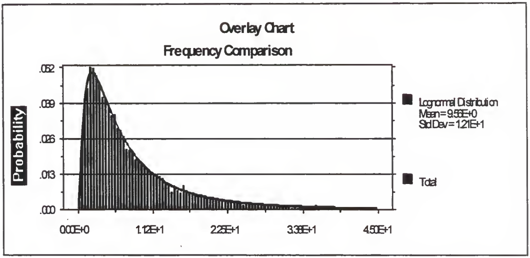


Figure 6-1: Set 9 Output and Distribution Fit for Ra-226

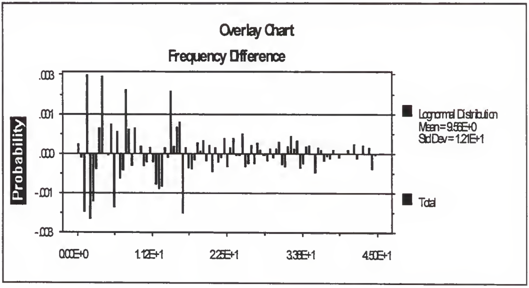


Figure 6-2: Difference Chart for Ra-226 Set 9

<u>Lead-210 Analysis on 1990 FIPR Data</u>

The lead-210 analyses on the 1990 FIPR data was performed in the same manner as the radium-226 above. The input data, represented in spreadsheet form, is presented in Table 6-5 below. Table 6-6 is the presentation or the distribution data for the various

Table 6-5: Input Spreadsheet Data for Lead-210 Dose Calculation (Guidry et al., 1990)

	DCF	5.40E-03	(mrem/pCi)
Diet Item	**Intake (g/day)**	**Concentration (pCi/kg)**	**Intake (pCi/yr)**
Broccoli	3.51	60.09	76.98
LEAFY			
Cabbage	7.04	122.61	315.06
Collard Greens	0.45	33.29	5.47
Lettuce	23.38	75.56	644.81
Mustard Greens	0.45	0.50	0.08
Spinach	3.28	166.49	199.32
Turnip Greens	0.45	40.48	6.65
SEEDS/GRAINS			
Blackeyed Peas	5.61	22.00	45.05
Rice	22.94	62.26	521.31
Yellow Corn	14.41	22.00	115.71
ROOTS			
Carrot	2.92	5.97	6.36
Onion	4.19	4.70	7.19
Radish	0.32	4.70	0.55
Turnip	0.42	10.22	1.57
GENERAL			
Cucumber	2.62	8.00	7.65
Green Beans	8.80	8.00	25.70
Green Peppers	1.99	8.00	5.81
Strawberries	1.23	456.19	204.81
Tomato	25.18	8.00	73.53
Watermelon	3.44	8.00	10.04
Squash/Zucchini	1.26	8.00	3.68
Totals	133.89		2277.31957
Total Diet	3071.81		

Dose

Non-Sampled	9.07E+00 mrem/yr
Sampled	1.23E+01 mrem/yr
Total	2.14E+01 mrem/yr

Table 6-6: Table of Input and Output Distributions for Lead-210

	Intake	Concentration	DCF	Dose
Set 1	LN	LN	LN	LN
Set 2	G	LN	LN	LN
Set 3	G	G	LN	LN
Set 4	G	G	G	Beta
Set 5	LN	G	G	Beta
Set 6	LN	LN	G	G
Set 7	LN	G	LN	LN
Set 8	G	LN	G	Beta
Set 9	LN	LN	LN	LN

variables and the final dose. Table 6-7 shows the statistics of interest for the output distributions.

Figure 6-3 is shown as the set 9 for this family of distribution analyses. It is believed to be the most probable outcome of dose. Figure 6-4 shows the Crystal Ball output graph of the difference chart. This graph illustrates the difference between the output dose distribution and the closest fit approximation determined by the program and its subsequent Chi-squared test of fit for the curve.

Table 6-7: Statistical Comparison of Various Data for Lead-210

	Mean	Std Dev	Skewness	Kurtosis	COF	Range Width
Set 1	21.4	2.25	0.32	3.18	0.11	17.6
Set 2	21.4	2.25	0.29	3.1	0.11	18.2
Set 3	21.3	2.25	0.37	3.27	0.11	19.6
Set 4	21.3	2.25	0.06	3.04	0.11	18.4
Set 5	21.4	2.27	0.05	3.06	0.11	19
Set 6	21.3	2.28	0.08	2.99	0.11	19
Set 7	21.4	2.25	0.33	3.18	0.11	18.2
Set 8	21.4	2.28	0.07	3.05	0.11	18.1
Set 9	34.7	43.9	5.18	56.66	1.25	965

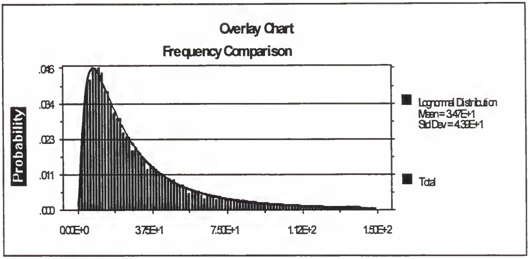


Figure 6-3: Set 9 Output and Distribution Fit for Pb-210

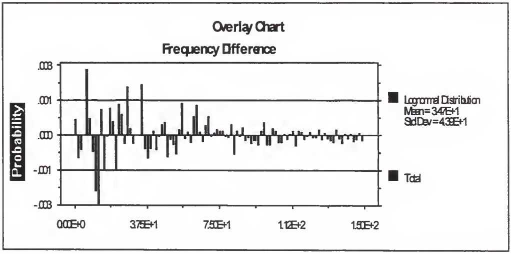


Figure 6-4: Difference Chart for Lead-210 Set 9

Grocery Store Data Analysis

Lead-210

The analyses on the grocery store data followed the same approach and methodology as that utilized to perform the analyses on the original FIPR data. Two radionuclides were considered: lead-210 and radium-226. In fact, like the original study,

this study counted the foods for two radionuclides: lead-210 and radium-226. The original study provided the data but no analysis on the polonium due to the lack of literature and values for the nonsampled food items and the concentration or dose that could be assigned to these values. A literature search did not turn up enough data to support analysis of this third radionuclide; therefore, similar to the original study, no analyses were performed in relation to it.

Each variable is assigned a value. Intake data were obtained from a literature search of previous studies and databases on consumption in the United States. The concentration data for the various foods was obtained by experimental measurement discussed in the fourth chapter. Dose conversion factors were obtained from Federal Regulatory Guide # 11. All of these data were provided different distributions to obtain the nine sets of dose distributions and analyses. Table 6-8 shows the input to Crystal Ball.

Table 6-9 illustrates the input variable and the output distributions obtained for the various sets tested. Table 6-10 shows the statistical output for the various sets. Figure 6-5 is the forecast output of the Crystal Ball program for the 9th set, and Figure 6-6 shows the difference between the programs best fit and the output data.

Radium-226

Table 6-11 illustrates the data input to the program to run the simulation and obtain results. Table 6-12 is the description of the distribution results. Table 6-13 shows the output statistics. Figure 6-7 is the frequency output for set 9, and Figure 6-8 is the difference comparison of this frequency output to the best fit distributions.

Table 6-8: Input Spreadsheet Data for Lead-210 Dose Calculation

	DCF	5.40E-03	(mrem/pCi)
Diet Item	**Intake (g/day)**	**Concentration (pCi/kg)**	**Intake (pCi/yr)**
Broccoli	3.51	829	1062.07
LEAFY			
Cabbage	7.04	858	2204.72
Collard Greens	0.45	1372	225.35
Lettuce	23.38	1237	10556.19
Mustard Greens	0.45	1622	266.41
Spinach	3.28	422	505.22
Turnip Greens	0.45	941	154.56
SEEDS/GRAINS			
Blackeyed Peas	5.61	494	1011.54
Rice	22.94	654	5476.01
Yellow Corn	14.41	506	2661.38
ROOTS			
Carrot	2.92	555	591.52
Onion	4.19	599	916.08
Radish	0.32	580	67.74
Turnip	0.42	401	61.47
GENERAL			
Cucumber	2.62	47082	45024.52
Green Beans	8.80	3837	12324.44
Green Peppers	1.99	431	313.06
Strawberries	1.23	715	321.00
Tomato	25.18	1011	9291.80
Watermelon	3.44	776	974.35
Squash/Zucchini	1.26	613	281.92
Totals	133.89		94291.34
Total Diet	3071.81		

Dose

Non-Sampled	9.07E+00 mrem/yr
Sampled	5.09E+02 mrem/yr
Total	5.18E+02 mrem/yr

Table 6-9: Table of Input and Output Distributions for Lead-210

	Intake	Concentration	DCF	Dose
Set 1	LN	LN	LN	LN
Set 2	G	LN	LN	Gamma
Set 3	G	G	LN	Gamma
Set 4	G	G	G	Gamma
Set 5	LN	G	G	Gamma
Set 6	LN	LN	G	Gamma
Set 7	LN	G	LN	LN
Set 8	G	LN	G	Gamma
Set 9	LN	LN	LN	LN

Table 6-10: Statistical Comparison of Various Dose Rate Results Data for Lead-210

	Mean	Std Dev	Skewness	Kurtosis	COF	Range Width
Set 1	518	63.9	0.41	3.26	0.12	563
Set 2	518	64.6	0.36	3.19	0.12	529
Set 3	518	64.2	0.37	3.23	0.12	541
Set 4	518	64.7	0.2	3.08	0.12	588
Set 5	518	63.9	0.21	3.12	0.12	541
Set 6	517	63.8	0.22	3.14	0.12	576
Set 7	518	64.6	0.39	3.26	0.12	529
Set 8	518	63.7	0.21	3.16	0.12	529
Set 9	854	1070	6.02	86.32	1.27	3150

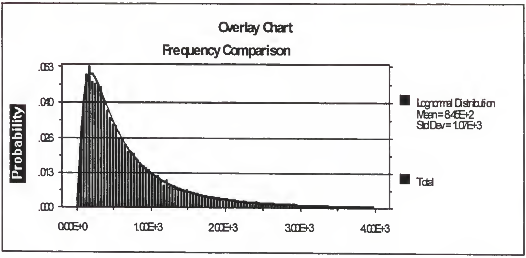


Figure 6-5: Set 9 Output and Distribution Fit for Pb-210

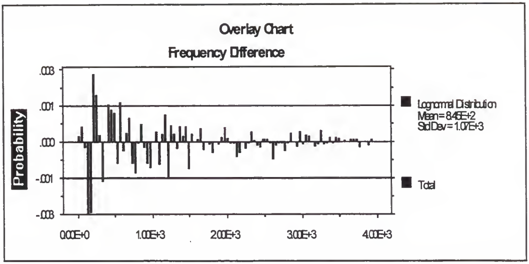


Figure 6-6: Difference Chart for Lead-210 Set 9

Overall Analysis

The above sets were each run with 20,000 trials each to decrease statistical error and improve comparability. The data show some very interesting results when compared to each other and then when compared to overall annual dose to an individual.

Dose Data Comparison

Lead-210 exhibited the highest dose in both the original set of data and the grocery store data. The original FIPR 1990 report data yielded a dose from ingestion of lead 210 of 21.4 mrem/yr for sets 1 through 8 and 34.7 mrem/yr for set 9. The grocery store data yielded a dose to the individual of 518 mrem/yr for sets 1 through 8 and 854 mrem/yr for set 9 individual of 877mrem/yr. The dose calculated from the grocery store data was 24 times higher than that calculated from the 1990 FIPR data.

Table 6-11: Input Spreadsheet Data for Radium-226 Dose Calculation (Grocery Data)

Diet Item	DCF Intake (g/day)	1.30E-03 Concentration (pCi/kg)	(mrem/pCi) Intake (pCi/yr)
Broccoli	3.51	5.00	6.406
LEAFY			
Cabbage	7.04	6.00	15.418
Collard Greens	0.45	6.00	0.986
Lettuce	23.38	4.00	34.135
Mustard Greens	0.45	17.00	2.792
Spinach	3.28	20.00	23.944
Turnip Greens	0.45	6.00	0.986
SEEDS/GRAINS			
Blackeyed Peas	5.61	3.00	6.143
Rice	22.94	2.00	16.746
Yellow Corn	14.41	6.00	31.558
ROOTS			
Carrot	2.92	4.00	4.263
Onion	4.19	4.00	6.117
Radish	0.32	4.00	0.467
Turnip	0.42	1177.00	180.434
GENERAL			
Cucumber	2.62	9.00	8.607
Green Beans	8.80	7.00	22.484
Green Peppers	1.99	4.00	2.905
Strawberries	1.23	4.00	1.796
Tomato	25.18	3.00	27.572
Watermelon	3.44	2.00	2.511
Squash/Zucchini	1.26	4.00	1.840
Totals	133.89		398.109
Total Diet	3071.81		

Dose

Non-Sampled	2.18E+00 mrem/yr
Sampled	5.18E-01 mrem/yr
Total	2.70E+00 m/rem/yr

Table 6-12: Table of Input and Output Distributions for Radium-226 (Grocery Data)

	Intake	Concentration	DCF	Dose
Set 1	LN	LN	LN	LN
Set 2	G	LN	LN	Gamma
Set 3	G	G	LN	Gamma
Set 4	G	G	G	Beta
Set 5	LN	G	G	Beta
Set 6	LN	LN	G	Beta
Set 7	LN	G	LN	Gamma
Set 8	G	LN	G	Beta
Set 9	LN	LN	LN	LN

Table 6-13: Statistical Comparison of Various Dose Rate Results Data for Radium-226 (Grocery Data)

	Mean	Std Dev	Skewness	Kurtosis	COF	Range Width
Set 1	2.7	0.273	0.31	3.22	0.1	2.27
Set 2	2.7	0.275	0.31	3.29	0.1	2.25
Set 3	2.7	0.274	0.31	3.15	0.1	2.06
Set 4	2.7	0.27	0.02	2.95	0.1	2.1
Set 5	2.7	0.273	0	2.95	0.1	2.21
Set 6	2.7	0.272	0.04	3.03	0.1	2.16
Set 7	2.7	0.271	0.3	3.21	0.1	2.45
Set 8	2.7	0.272	-0.01	3.02	0.1	2.09
Set 9	4.38	5.52	5.6	69.91	1.28	150

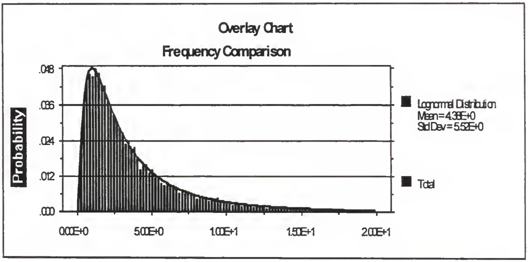


Figure 6-7: Set 9 Output and Distribution Fit for Radium-226 (Grocery Data)

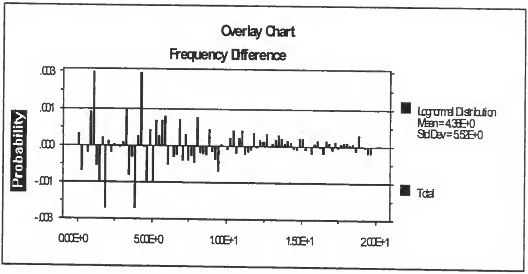


Figure 6-8: Difference Chart for Radium-226 Set 9 (Grocery Data)

The dose from the grocery store data is believed to be higher for two reasons. The peak measured on the original analysis was the 40 KeV peak. The peak measured on the grocery store analysis was the 10.8 KeV peak. This peak was measured because of the successful recognition of this peak by the GammaVision program for this peak for the lead-210 radionuclide. This 10.8 KeV peak yielded a significantly higher correction factor than previously measured and observed for the alternate lead-210 peak.

Radium-226 had the lowest dose per year of both radionuclides considered. The output from the analysis of the 1990 FIPR data yielded a dose to the individual from radium-226 of 5.91 mrem/yr for sets 1 through 8 and 9.56 for set 9. The grocery store data provided an individual dose that was lower than the FIPR data. The grocery store data dose to the individual was calculated to be 2.7 mrem/yr for sets 1-8 and 4.38 for set 9. The dose calculated from the grocery store data was 45% of the dose calculated for the original FIPR dose calculation.

Comparing the dose to the individual from radium-226 and lead-210 from the FIPR data, it was calculated that dose from lead-210 was 3.6 times higher than the individuals dose from radium-226. A similar comparison of doses for the grocery store data concluded that the individual's dose attributable to lead-210 was 191 times greater than that attributable to radium-226

Some of the differences between doses attributable to the radionuclides can be traced back to their reported dose conversion factors. Lead-210 is almost three times larger than radium-226. Consider this factor with the fact that lead-210 had some individual samples with high counts and a higher intersample comparison should be expected.

Comparison of Distributions and Statistics

The dose conversion factor distribution appears to have a strong effect on the dose distribution. A sensitivity analysis was performed on the various variables with the outcome determining that the dose conversion factor was over 10 times more sensitive to the output distribution that any other variable. The data reveal that multiplying three lognormal distribution yields a lognormal output distribution each time. Multiplying three normal distributions times each other provides a normal distribution for the output dose in two cases and a beta distribution in two other cases. Multiplying a mixture of lognormal distributions and normal distributions does not necessarily yield either of these distributions as an output. The best fit to the dose distribution output in the preceding case is illustrated above to be a lognormal, a normal, a beta, or a gamma distribution.

The beta distribution is a very flexible distribution commonly utilized to represent variability over a wide range (Decisioneering, 1996). This distribution can assume a wide variety of shapes when the values of alpha a beta are varied.

The gamma distribution is related to the lognormal distribution and is used sometimes to represent pollutant concentrations and precipitation quantities.

Set 9, in all four sets of analyses, was utilized to represent the most accurate quantity. The value of this dose in all four groups was significantly higher that the other eight sets in that group under consideration. The primary reason for this is the change in the dose conversion factor. Being the most sensitive variable and the large skewness introduced due to the determination of an accurate shape of this curve from a discussion with Dr. Eckerman, this provided an output dose distribution different from the other sets.

Conclusions

The purpose of this chapter was accomplished by a literature search that described the applicable and relevant literature to determine the committed effective dose equivalent, the term to describe the extended dose to an individual based on intake of a specific radionuclide. The data previously obtained were then analyzed with the original data and a comparison is provided.

The shape of various dose distributions to individuals was determined for nine combinations of variable distributions in each of the two radionuclides in each of the two studies. The data from one study came from a previous 1990 FIPR report. The data for the other study were determined by experimental measurement from an earlier chapter in this series. The Crystal Ball program and monte carlo sampling method inherent to it were utilized to perform these analyses for each set of distributions.

The average individual annual dose, as stated in the introduction, is 360 mrem/yr. Lead-210 measurement is 518 mrem/yr for eight sets of analyses on grocery store samples and 854 mrem/yr for the most likely distribution scenario. The lead-210 dose to an individual from the analysis of the FIPR data was 34.7 mrem/yr for the case 9 and 21.4 mrem/yr for all others. The case 9 set of variable distributions is believed to be the most likely dose output. This output distribution is described by a lognormal distribution. Many reasons were observed for the higher value from the experimental data dose determination. A different peak measurement and a higher correction factor were both significant factors as well as the fact that the 10.8 KeV is at the lower edge of analysis for the system. In defense of a higher lead-210 dose, the original 1990 FIPR report chose not to use grocery store data due to the fact that only single replicates were being measured and the alternate fact that the dose obtained was 200 times greater than the other measurements.

The radium-226 individual dose measurements for the case 9, the most likely case, also followed a lognormal distribution. The values of the dose to the individual were significantly lower than the lead-210 values. The dose for the FIPR data was 5.91 mrem/yr for eight cases and 9.56 mrem/yr for the ninth and most likely case. The grocery store data provided a dose to the individual that measured 2.7 mrem/yr for 8 sets and 4.38 mrem/yr for the most likely case. These data, compared to the 360 mrem/yr expected dose from natural sources, are less than 3% for all radium-226 measurements.

The distributions described by the various analyses included normal, lognormal, beta, and gamma. The output, dose, and distributions were strongly influenced by the distribution assigned to the dose conversion factor variable.

This chapter is designed to determine a probabilistic dose to individuals from foods bought at local stores in Gainesville, Florida. The first chapter provided the introduction of a probabilistic dose approach. The second chapter described the literature search for the overall dissertation to determine the references that were used for each section. The third chapter determined the dietary intake values to be used and the most probable distribution to describe them. The fourth chapter described the actual experimentation performed to determine both the concentration of specific radionuclides in the various foods measured and the distribution to describe this concentration. The fifth chapter described the methodology to determine the dose conversion factor (DCF) value and distribution. The purpose of this chapter was to determine the value and distribution to describe the dose to an individual based on the values obtained in the previous chapters. The next and final chapter provides a conclusion and recommendations for future research in this area.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

This is the seventh and the last chapter intended to design and implement a methodology to determine a probabilistic radiation dose to individuals. This methodology is analyzed by application to data experimentally determined from foods bought at local stores in Gainesville, Florida.

The first chapter in the series provided the introduction of a probabilistic dose approach. The explanation of how the current approach to individual dose determination was deterministic and resulted in a dose with a single number describing it. A probabilistic approach was explained and how this yielded a dose that was described with a distribution.

The second chapter described the literature search for the overall dissertation to determine the references that were used for each section. This general literature search provided the basis for the background data utilized for the remainder of the dissertation.

The third chapter determined the dietary intake values to be used and the most probable distribution to describe them. These values and data were derived from literary sources of previous studies and dietary surveys performed in the United States.

The fourth chapter described the actual experimentation performed to determine both the concentration of specific radionuclides in the various foods measured and the distribution to describe this concentration. Samples from three different local stores were analyzed to determine concentrations of radium-226 and lead-210 in the foods. An

additional study was performed to determine experimentally the type of distribution to describe best the concentration in foods.

The fifth chapter described the methodology to determine the dose conversion factor (DCF) value and distribution. Literary sources as well as direct conversation with people at the cutting edge of dose conversion factor determination provided the data obtained in this chapter for the value and distributions to describe the dose conversion factor.

The sixth chapter determined the value and distribution to describe the dose to an individual based on the values obtained in the previous chapters. The Crystal Ball program was utilized to perform groups of analyses on both original 1990 Florida Institute of Phosphate Research data as well as grocery store data.

Crystal Ball is like any computer program. Good information in will yield good information out. The data that were measured had numerous data points that provided no counts at the specific peaks that were being observed. Minimum detectable activity numbers were input for these data points to provide for a large and, therefore conservative from a safety standpoint, dose estimate. The unsampled data points provided another source of error which was overcome by reference to previous work and data manipulation to provide a dose for these data points. This, however, provides another possible source for higher dose output. The Crystal Ball program provided an accurate way to sample the input to provide a distribution output that was as accurate as the input provided.

The grocery store data showed a lognormal distribution for lead-210 with an average dose 854 mrem/yr for the most probable case and 518 mrem/yr for all other eight

cases. The FIPR data illustrated a lead-210 mean of 34.7 mrem/yr for the most probable case and 21.4 consistently for all other cases.

The reasons for such a high lead-210 dose is due to many factors: different peak counted, different calibration or correction factor, and the peak measured being at the lower edge of the detector's measurement limit. This number, as stated before, seems abnormally high and should be verified with other analyses.

The grocery store radium-226 measurement for individual dose, by comparison, was 2.7 mrem/yr for eight cases and 4.38 mrem/yr for the ninth and most probable case. This value was lower than the individual dose value obtained from the data from the 1990 FIPR report. This report yielded an individual dose of 5.91 mrem/yr for eight cases and 9.56 mrem/yr for the most probable case. The most probable dose scenarios followed a lognormal distribution that closely approximated the dose conversion factor input distribution.

The numbers for radium-226 are very similar to those obtained by FIPR in the 1990 report and so support their data as well as extending the database. The lead-210 measured in this report are consistent with the previous report in the fact that the lead-210 general foods category radiation dose calculation from the grocery store samples ranged from 2 to 200 times higher than the literature value (Guidry et al., 1990).

The methodology of using Crystal Ball and probabilistic dose calculation was successfully implemented in the previous chapter. The inclusion of distributions to account for fluctuations, errors and variations was very useful and provided a higher initial dose than the deterministic approach in the previous FIPR paper (Guidry et al., 1990). The distribution groups allow for flexibility should future research determine more

accurate distributions for the variables. Additionally, the output distributions provide a visual aid for the public and researchers to understand radiation dose and the fact that it is a range and not just one number!

Future analyses should, if possible, include the location of where samples are grown. Additional measurements should be taken to determine and confirm the normal distribution assigned to the food concentration. Additional Crystal Ball analysis should be performed on the calculational parameters and, therefore, the solution for the dose conversion factor formula. This would provide a more accurate distribution for the dose per unit intake factor. An analysis to determine the differences and advantages of the various dose conversion factors should be considered. A study should also be undertaken to determine the effect on changing the various distributions on the final dose. A determination should be made as to what may be the cause for the elevated measurements for lead-210. These are a few suggestions on the direction that this work should take in the future.

APPENDIX A
DATA SHEETS

Item	Store	Weight	Time Counted	Detector	File Saved
Beef	Publix	556.6	34187.1	4	beef.spc
Beef Kidney	Publix	449.2	86362.4	4	bfkid.spc
Black-Eyed Peas	Publix	455.35	86437.5	2	bleypeas
Black-Eyed Peas	Albertsons	264.3	72000	2	bepe.spc
Black-Eyed Peas	Winn Dixie	473.8	34098.9	4	bley3.spc
Brazil Shells	Publix	304.2	43149	2	bznutssh.spc
Broccoli	Publix	267	34167.9	4	brocc1.spc
Broccoli	Albertsons	192.4	71946.1	2	broc2.spc
Broccoli	Winn Dixie	324.4	34124.9	2	broc3.spc
Cabbage	Publix	210.45	34187.4	2	cabb.spc
Cabbage	Albertsons	179.3	34155.1	4	cabb2.spc
Cabbage	Winn Dixie	214.15	34122.6	4	cabb3.spc
Carrots	Publix	286.9	34187.8	2	carr.spc
Carrots	Albertsons	421.1	71940.8	4	carr2.spc
Carrots	Winn Dixie	365.9	34061.3	4	carr3.spc
Cauliflower	Publix	268.8	34187.4	4	caul.spc
Cauliflower	Albertsons	154.45	34187.5	2	caul2.spc
Cauliflower	Winn Dixie	396.1	34167.7	2	caul3.spc
Collard Greens	Publix	140.35	34187.9	4	cogr.spc
Collard Greens	Albertsons	421.15	71940.8	2	cogr2.spc
Collard Greens	Winn Dixie	136.6	34104.7	2	cogr3.spc
Corn	Publix	289.85	34194.1	2	corn.spc
Corn	Albertsons	199.6	34187.3	4	corn2.spc
Corn	Winn Dixie	418.4	34051.1	4	corn3.spc
Cucumber	Publix	347.55	34167.9	2	cucu1.spc
Cucumber	Albertsons	257.6	71942.7	2	cucu2.spc
Cucumber	Winn Dixie	324.2	34087.2	2	cucu3.spc
Eggplant	Publix	238.4	34187.8	2	eggp.spc
Eggplant	Albertsons	231.7	71970.2	4	egpl2.spc
Eggplant	Winn Dixie	130.3	34089	2	eggp3.spc
Grapefruit	Publix	448.1	34186.8	4	grap.spc
Grapefruit	Albertsons	317.6	71944	4	grap2.spc
Grapefruit	Winn Dixie	422.5	34089	4	grap3.spc

Item	Store	Weight	Time Counted	Detector	File Saved
Green Beans	Publix	216.7	34186.9	4	grbr.spc
Green Beans	Albertsons	250	71971.9	2	grbe2.spc
Green Beans	Winn Dixie	338	34036.9	2	grbe3.spc
Green Onions	Publix	97.2	34187.8	4	gron.spc
Green Onions	Albertsons	89.1	71972.1	4	gron2.spc
Green Onions	Winn Dixie	195.15	34100.7	2	gron3.spc
Green Peppers	Publix	321	34186.9	2	grpe.spc
Green Peppers	Albertsons	287.5	71941.8	4	grpe2.spc
Green Peppers	Winn Dixie	415.75	34097.7	4	grpe3.spc
Irish Creamer Potatoes	Publix	353.75	34186	4	icp.spc
Lemons	Publix	316.9	43176.9	4	lem.spc
Lemons	Albertsons	238.75	71941.8	2	lemo2.spc
Lemons	Winn Dixie	372.7	34154.8	4	lemo3.spc
Lettuce	Publix	218.8	43181.5	2	lettw.spc
Lettuce	Albertsons	201.1	71944	2	lett2.spc
Lettuce	Winn Dixie	319.45	34099.5	2	lett3.spc
Lima Beans	Publix	362.7	43182.2	2	lima.spc
Lima Beans	Albertsons	358.65	71942.7	4	libe2.spc
Lima Beans	Winn Dixie	382.6	34040.6	2	libe3.spc
Mustard Greens	Albertsons	81.35	34187.5	4	mugr.spc
Okra	Publix	180.5	34186	2	okra.spc
Okra	Albertsons	240.5	71970.2	2	okra2.spc
Okra	Winn Dixie	320.3	34167.4	4	okra4.spc
Onions	Publix	335.6	43181.9	2	onio.spc
Onions	Albertsons	323.15	71979.8	2	onio2.spc
Onions	Winn Dixie	332.1	34037.1	4	onio3.spc
Oranges	Publix	446.9	43176.9	2	oran.spc
Oranges	Albertsons	381.3	71973.3	2	oran2.spc
Oranges	Winn Dixie	379.6	34030.4	4	oran3.spc
Parsley	Publix	71.25	43179.7	4	pars.spc
Parsley	Albertsons	17.8	34181	2	pars2.spc
Parsley	Winn Dixie	175.75	34062	2	pars3.spc

Item	Store	Weight	Time Counted	Detector	File Saved
Peas	Publix	263.2	43180.5	2	peas.spc
Peas	Albertsons	289.35	71970.9	4	peas2.spc
Peas	Winn Dixie	342.6	33922.1	2	peas3.spc
Pole Beans	Publix	267.15	34186.8	2	pb.spc
Pole Beans	Winn Dixie	416.5	34057.6	4	pobe3.spc
Potato	Publix	398	43179.7	2	pot.spc
Potato	Albertsons	254.45	86366.8	2	pot2.spc
Potato	Winn Dixie	390.3	34154.9	2	pot3.spc
Purple Hull Peas	Publix	391.05	43182.3	4	php.spc
Purple Hull Peas	Winn Dixie	430.3	34200	2	crpe3.spc
Radishes	Publix	333.7	34128.8	4	rad.spc
Radishes	Albertsons	170.1	71968.7	4	radi2.spc
Radishes	Winn Dixie	310.3	34100.9	4	rad3.spc
Red Potatoes	Publix	348.15	43182.2	4	rpot.spc
Red Potatoes	Winn Dixie	371.8	34086.4	4	rpot3.spc
Rice	Publix	518.55	43182	4	rc.spc
Rice	Albertsons	446.8	71968.6	2	rice2.spc
Rice	Winn Dixie	583.85	34078.7	2	rice3.spc
Spinach	Publix	99.85	34185.9	4	sp.spc
Spinach	Albertsons	69.3	22702.8	4	spin2.spc
Spinach	Winn Dixie	484.7	34077.8	4	spin3.spc
Strawberries	Publix	348.75	34126.7	2	stra.spc
Strawberries	Albertsons	278.5	71973.3	4	straw2.spc
Strawberries	Winn Dixie	337.1	34051.8	2	straw3.spc
Swiss Chard	Publix	173.65	34187.1	2	swch.spc
Tangerine	Albertsons	276	34155.2	2	tan2.spc
Tangerine	Winn Dixie	399.85	34109.5	4	tan3.spc
Tomatoes	Publix	358.8	43181.4	4	tomat.spc
Tomatoes	Albertsons	376.05	34191.8	2	tom2w.spc
Tomatoes	Winn Dixie	434.4	34048	2	5om3.spc
Turnip Greens	Publix	135.65	43183.1	4	tg.spc
Turnip Greens	Albertsons	313.65	34181.8	4	tugr2.spc
Turnip Greens	Winn Dixie	564.2	34185.4	2	tugr3.spc

Item	Store	Weight	Time Counted	Detector	File Saved
Turnip Root and Green	Publix	189.65	34186	2	trag.spc
Turnip Roots	Publix	275.1	43148.7	4	turnroots.spc
Turnip Roots	Albertsons	0.3	71972.2	2	turn2.spc
Watermelon	Publix	463.6	43182.4	2	wm.spc
Watermelon	Albertsons	396	34187.4	2	wat2.spc
Yellow Corn	Publix	324.6	43182.1	2	yc.spc
Yellow Corn	Albertsons	234.75	34191.7	4	yc2.spc
Yellow Corn	Winn Dixie	386.6	34167.8	2	yeco3.spc
Yellow Squash	Publix	331.6	43183.1	2	yesq.spc
Yellow Squash	Albertsons	219.4	86366.8	4	yesq2.spc
Yellow Squash	Winn Dixie	361.9	33914.5	4	yellow3.spc
Zucchini	Publix	394.3	43180.5	4	zucc.spc
Zucchini	Albertsons	256.4	71971.9	4	zucc2.spc
Zucchini	Winn Dixie	368.7	34167.8	4	zucc3.spc
Brazil Nuts		226	86369	4	bznuts.spc

	Pb-210 Peaks	
	Pb-210	10.8 KeV
Item	Net (Counts)	Error
Beef	0	0
Beef Kidney	126	47
Black-Eyed Peas	0	0
Black-Eyed Peas	0	0
Black-Eyed Peas		
Brazil Shells	0	0
Broccoli	0	0
Broccoli	0	0
Broccoli	0	0
Cabbage	0	0
Cabbage	0	0
Cabbage	45	12
Carrots	0	0
Carrots	91	45
Carrots	0	0
Cauliflower	105	27
Cauliflower	0	0
Cauliflower	0	0
Collard Greens	43	26
Collard Greens	0	0
Collard Greens	0	0
Corn	0	0
Corn	0	0
Corn	0	0
Cucumber	4779	142
Cucumber	182	35
Cucumber	0	0
Eggplant	0	0
Eggplant	0	0
Eggplant	0	0
Grapefruit	0	0
Grapefruit	0	0
Grapefruit	0	0

	Pb-210 Peaks	
	Pb-210	10.8 KeV
Item	Net (Counts)	Error
Green Beans	437	59
Green Beans	211	37
Green Beans	0	0
Green Onions	0	0
Green Onions	0	0
Green Onions	0	0
Green Peppers	0	0
Green Peppers	0	0
Green Peppers	0	0
Irish Creamer Potatoes	0	0
Lemons	0	0
Lemons	0	0
Lemons	0	0
Lettuce	0	0
Lettuce	0	0
Lettuce	0	0
Lima Beans	76	0
Lima Beans	76	47
Lima Beans	0	0
Mustard Greens	41	29
Okra	0	0
Okra	0	0
Okra	28	8
Onions	0	0
Onions	0	0
Onions	0	0
Oranges	0	0
Oranges	100	38
Oranges	0	0
Parsley	0	0
Parsley	0	0
Parsley	0	0

Item	Pb-210 Peaks Pb-210 Net (Counts)	 10.8 KeV Error
Peas	0	0
Peas	49	44
Peas	0	0
Pole Beans	0	0
Pole Beans	0	0
Potato	0	0
Potato	0	0
Potato	0	0
Purple Hull Peas	0	0
Purple Hull Peas	0	0
Radishes	19	30
Radishes	143	43
Radishes	26	7
Red Potatoes	0	0
Red Potatoes	37	12
Rice	0	0
Rice	122	39
Rice	0	0
Spinach	0	0
Spinach	0	0
Spinach	0	0
Strawberries	0	0
Strawberries	0	0
Strawberries	0	0
Swiss Chard	0	0
Tangerine	0	0
Tangerine	0	0
Tomatoes	0	0
Tomatoes	0	0
Tomatoes	87	18
Turnip Greens	69	33
Turnip Greens	0	0
Turnip Greens	79	20

	Pb-210 Peaks	
	Pb-210	10.8 KeV
Item	Net (Counts)	Error
Turnip Root and Green	0	0
Turnip Roots	53	33
Turnip Roots	0	0
Watermelon	0	0
Watermelon	0	0
Yellow Corn	0	0
Yellow Corn	0	0
Yellow Corn	0	0
Yellow Squash	0	0
Yellow Squash	135	44
Yellow Squash	0	0
Zucchini	0	0
Zucchini	0	0
Zucchini	0	0
Brazil Nuts	235	86

	Ra-226 Peaks					
	Pb-214	295 KeV	Pb-214	352 KeV	Bi-214	609 KeV
Item	Net (Counts)	Error	Net (Counts)	Error	Net (Counts)	Error
Beef	0	0	0	0	0	0
Beef Kidney	0	0	0	0	271	30
Black-Eyed Peas	0	0	0	0	0	0
Black-Eyed Peas	0	0	0	0	0	0
Black-Eyed Peas						
Brazil Shells	495	42	904	43	541	31
Broccoli	0	0	0	0	0	0
Broccoli	0	0	0	0	0	0
Broccoli	39	32	0	0	69	29
Cabbage	0	0	0	0	0	0
Cabbage	96	32	248	30	233	22
Cabbage	0	0	82	29	0	0
Carrots	0	0	0	0	0	0
Carrots	140	44	181	42	0	0
Carrots	0	0	0	0	95	20
Cauliflower	0	0	0	0	0	0
Cauliflower	0	0	0	0	0	0
Cauliflower	0	0	0	0	0	0
Collard Greens	0	0	81	25	0	0
Collard Greens	0	0	0	0	0	0
Collard Greens	0	0	0	0	0	0
Corn	0	0	0	0	0	0
Corn	0	0	0	0	0	0
Corn	0	0	0	0	0	0
Cucumber	0	0	0	0	0	0
Cucumber	51	31	0	0	0	0
Cucumber	0	0	0	0	0	0
Eggplant	0	0	0	0	0	0
Eggplant	75	44	271	37	237	28
Eggplant	0	0	0	0	0	0
Grapefruit	0	0	0	0	0	0
Grapefruit	0	150	39	0	0	0
Grapefruit	0	0	102	26	80	23

	Ra-226 Peaks					
	Pb-214	295 KeV	Pb-214	352 KeV	Bi-214	609 KeV
Item	Net (Counts)	Error	Net (Counts)	Error	Net (Counts)	Error
Green Beans	0	0	0	0	0	0
Green Beans	0	0	0	0	0	0
Green Beans	0	0	0	0	0	0
Green Onions	0	0	0	0	0	0
Green Onions	0	0	227	38	0	0
Green Onions	0	0	0	0	0	0
Green Peppers	0	0	0	0	0	0
Green Peppers	0	0	387	411	303	30
Green Peppers	0	0	0	0	0	0
Irish Creamer Potatoes	0	0	37	0	0	0
Lemons	0	0	0	67	27	0
Lemons	0	0	0	0	0	0
Lemons	0	0	0	0	6	7
Lettuce	0	0	0	0	0	0
Lettuce	0	0	0	0	0	0
Lettuce	0	0	0	0	0	0
Lima Beans	0	0	299	0	0	0
Lima Beans	180	43	299	40	0	0
Lima Beans	0	0	0	0	0	0
Mustard Greens	0	0	189	26	0	0
Okra	0	0	0	0	0	0
Okra	0	0	0	0	0	0
Okra	0	0	0	0	0	0
Onions	0	0	0	0	0	0
Onions	0	0	0	0	0	0
Onions	0	0	0	0	0	0
Oranges	0	0	0	0	0	0
Oranges	0	0	0	0	0	0
Oranges	0	0	0	0	0	0
Parsley	0	0	100	29	0	0
Parsley	0	0	0	0	0	0
Parsley	0	0	0	0	0	0

	Ra-226 Peaks					
	Pb-214	295 KeV	Pb-214	352 KeV	Bi-214	609 KeV
Item	Net (Counts)	Error	Net (Counts)	Error	Net (Counts)	Error
Peas	0	0	0	0	0	0
Peas	0	0	163	38	0	0
Peas	0	0	0	0	0	0
Pole Beans	0	0	0	0	0	0
Pole Beans	0	0	75	24	0	0
Potato	0	0	0	0	0	0
Potato	0	0	0	0	0	0
Potato	0	0	0	0	0	0
Purple Hull Peas	66	33	0	0	0	0
Purple Hull Peas	0	0	0	0	0	0
Radishes	0	0	0	0	0	0
Radishes	0	0	203	37	187	27
Radishes	0	0	0	0	0	0
Red Potatoes	0	0	0	0	0	0
Red Potatoes	0	0	0	0	0	0
Rice	0	0	0	0	0	0
Rice	0	0	0	0	0	0
Rice	0	0	0	0	0	0
Spinach	0	0	0	0	0	0
Spinach	0	0	0	0	0	0
Spinach	0	0	0	0	0	0
Strawberries	0	0	0	0	0	0
Strawberries	0	0	0	0	242	25
Strawberries	0	0	0	0	0	0
Swiss Chard	0	0	0	0	0	0
Tangerine	0	0	0	0	0	0
Tangerine	0	0	0	0	114	15
Tomatoes	0	0	0	0	100	20
Tomatoes	0	0	0	0	0	0
Tomatoes	0	0	0	0	0	0
Turnip Greens	0	0	156	29	104	18
Turnip Greens	0	0	0	0	0	0
Turnip Greens	0	0	0	0	0	0

	Ra-226 Peaks					
	Pb-214	295 KeV	Pb-214	352 KeV	Bi-214	609 KeV
Item	Net (Counts)	Error	Net (Counts)	Error	Net (Counts)	Error
Turnip Root and Green	0	0	0	0	0	0
Turnip Roots	63	33	0	0	0	0
Turnip Roots	0	0	0	0	0	0
Watermelon	0	0	0	0	0	0
Watermelon	0	0	0	0	0	0
Yellow Corn	0	0	0	0	0	0
Yellow Corn	0	0	159	29	126	120
Yellow Corn	0	0	0	0	0	0
Yellow Squash	0	0	0	0	0	0
Yellow Squash	0	0	145	40	183	29
Yellow Squash	35	24	0	0	0	0
Zucchini	32	30	0	0	0	0
Zucchini	0	0	0	0	0	0
Zucchini	0	0	0	0	0	0
Brazil Nuts	4586	167	6936	105	4998	83

	Calibration Factors		Bkgnd Count		Minimum Det. Activity	
	Pb-210	Ra-226	Pb-210	Ra-226	Pb-210	Ra-226
Item	(pCi/cps)	(pCi/cps)	(counts)	(counts)	(pCi/g)	(pCi/g)
Beef	1.10E+05	1664	0.000637	0.0062	7.63E-02	3.60E-03
Beef Kidney	1.10E+05	1664	0.000637	0.0062	5.95E-02	2.81E-03
Black-Eyed Peas	3.40E+05	1670	0.0045	0.0016	4.82E-01	1.41E-03
Black-Eyed Peas	3.40E+05	1670	0.0045	0.0016	9.10E-01	2.67E-03
Black-Eyed Peas	1.10E+05	1664	0.000637	0.0062	8.98E-02	4.24E-03
Brazil Shells	3.40E+05	1670	0.0045	0.0016	1.02E+00	2.99E-03
Broccoli	1.10E+05	1664	0.000637	0.0062	1.59E-01	7.51E-03
Broccoli	3.40E+05	1670	0.0045	0.0016	1.25E+00	3.66E-03
Broccoli	3.40E+05	1670	0.0045	0.0016	1.08E+00	3.15E-03
Cabbage	3.40E+05	1670	0.0045	0.0016	1.66E+00	4.86E-03
Cabbage	1.10E+05	1664	0.000637	0.0062	2.37E-01	1.12E-02
Cabbage	1.10E+05	1664	0.000637	0.0062	1.99E-01	9.37E-03
Carrots	3.40E+05	1670	0.0045	0.0016	1.22E+00	3.56E-03
Carrots	1.10E+05	1664	0.000637	0.0062	6.96E-02	3.28E-03
Carrots	1.10E+05	1664	0.000637	0.0062	1.16E-01	5.49E-03
Cauliflower	1.10E+05	1664	0.000637	0.0062	1.58E-01	7.46E-03
Cauliflower	3.40E+05	1670	0.0045	0.0016	2.26E+00	6.62E-03
Cauliflower	3.40E+05	1670	0.0045	0.0016	8.82E-01	2.58E-03
Collard Greens	1.10E+05	1664	0.000637	0.0062	3.03E-01	1.43E-02
Collard Greens	3.40E+05	1670	0.0045	0.0016	5.71E-01	1.67E-03
Collard Greens	3.40E+05	1670	0.0045	0.0016	2.56E+00	7.49E-03
Corn	3.40E+05	1670	0.0045	0.0016	1.20E+00	3.53E-03
Corn	1.10E+05	1664	0.000637	0.0062	2.13E-01	1.00E-02
Corn	1.10E+05	1664	0.000637	0.0062	1.02E-01	4.80E-03
Cucumber	3.40E+05	1670	0.0045	0.0016	1.00E+00	2.94E-03
Cucumber	3.40E+05	1670	0.0045	0.0016	9.34E-01	2.74E-03
Cucumber	3.40E+05	1670	0.0045	0.0016	1.08E+00	3.16E-03
Eggplant	3.40E+05	1670	0.0045	0.0016	1.46E+00	4.29E-03
Eggplant	1.10E+05	1664	0.000637	0.0062	1.26E-01	5.97E-03
Eggplant	3.40E+05	1670	0.0045	0.0016	2.68E+00	7.86E-03
Grapefruit	1.10E+05	1664	0.000637	0.0062	9.48E-02	4.48E-03
Grapefruit	1.10E+05	1664	0.000637	0.0062	9.22E-02	4.35E-03
Grapefruit	1.10E+05	1664	0.000637	0.0062	1.01E-01	4.75E-03

	Calibration Factors		Bkgnd Count		Minimum Det. Activity	
	Pb-210	Ra-226	Pb-210	Ra-226	Pb-210	Ra-226
Item	(pCi/cps)	(pCi/cps)	(counts)	(counts)	(pCi/g)	(pCi/g)
Green Beans	1.10E+05	1664	0.000637	0.0062	1.96E-01	9.25E-03
Green Beans	3.40E+05	1670	0.0045	0.0016	9.62E-01	2.82E-03
Green Beans	3.40E+05	1670	0.0045	0.0016	1.04E+00	3.03E-03
Green Onions	1.10E+05	1664	0.000637	0.0062	4.37E-01	2.06E-02
Green Onions	1.10E+05	1664	0.000637	0.0062	3.29E-01	1.55E-02
Green Onions	3.40E+05	1670	0.0045	0.0016	1.79E+00	5.25E-03
Green Peppers	3.40E+05	1670	0.0045	0.0016	1.09E+00	3.19E-03
Green Peppers	1.10E+05	1664	0.000637	0.0062	1.02E-01	4.81E-03
Green Peppers	1.10E+05	1664	0.000637	0.0062	1.02E-01	4.83E-03
Irish Creamer Potatoes	1.10E+05	1664	0.000637	0.0062	1.20E-01	5.67E-03
Lemons	1.10E+05	1664	0.000637	0.0062	1.19E-01	5.63E-03
Lemons	3.40E+05	1670	0.0045	0.0016	1.01E+00	2.95E-03
Lemons	1.10E+05	1664	0.000637	0.0062	1.14E-01	5.38E-03
Lettuce	3.40E+05	1670	0.0045	0.0016	1.42E+00	4.16E-03
Lettuce	3.40E+05	1670	0.0045	0.0016	1.20E+00	3.50E-03
Lettuce	3.40E+05	1670	0.0045	0.0016	1.09E+00	3.20E-03
Lima Beans	3.40E+05	1670	0.0045	0.0016	8.56E-01	2.51E-03
Lima Beans	1.10E+05	1664	0.000637	0.0062	8.17E-02	3.85E-03
Lima Beans	3.40E+05	1670	0.0045	0.0016	9.14E-01	2.68E-03
Mustard Greens	1.10E+05	1664	0.000637	0.0062	5.22E-01	2.47E-02
Okra	3.40E+05	1670	0.0045	0.0016	1.93E+00	5.66E-03
Okra	3.40E+05	1670	0.0045	0.0016	1.00E+00	2.93E-03
Okra	1.10E+05	1664	0.000637	0.0062	1.33E-01	6.26E-03
Onions	3.40E+05	1670	0.0045	0.0016	9.26E-01	2.71E-03
Onions	3.40E+05	1670	0.0045	0.0016	7.44E-01	2.18E-03
Onions	1.10E+05	1664	0.000637	0.0062	1.28E-01	6.05E-03
Oranges	3.40E+05	1670	0.0045	0.0016	6.95E-01	2.04E-03
Oranges	3.40E+05	1670	0.0045	0.0016	6.31E-01	1.85E-03
Oranges	1.10E+05	1664	0.000637	0.0062	1.12E-01	5.30E-03
Parsley	1.10E+05	1664	0.000637	0.0062	5.31E-01	2.50E-02
Parsley	3.40E+05	1670	0.0045	0.0016	1.96E+01	5.74E-02
Parsley	3.40E+05	1670	0.0045	0.0016	1.99E+00	5.83E-03

	Calibration Factors		Bkgnd Count		Minimum Det. Activity	
	Pb-210	Ra-226	Pb-210	Ra-226	Pb-210	Ra-226
Item	(pCi/cps)	(pCi/cps)	(counts)	(counts)	(pCi/g)	(pCi/g)
Peas	3.40E+05	1670	0.0045	0.0016	1.18E+00	3.46E-03
Peas	1.10E+05	1664	0.000637	0.0062	1.01E-01	4.78E-03
Peas	3.40E+05	1670	0.0045	0.0016	1.02E+00	3.00E-03
Pole Beans	3.40E+05	1670	0.0045	0.0016	1.31E+00	3.83E-03
Pole Beans	1.10E+05	1664	0.000637	0.0062	1.02E-01	4.82E-03
Potato	3.40E+05	1670	0.0045	0.0016	7.80E-01	2.29E-03
Potato	3.40E+05	1670	0.0045	0.0016	8.63E-01	2.53E-03
Potato	3.40E+05	1670	0.0045	0.0016	8.95E-01	2.62E-03
Purple Hull Peas	1.10E+05	1664	0.000637	0.0062	9.67E-02	4.56E-03
Purple Hull Peas	3.40E+05	1670	0.0045	0.0016	8.11E-01	2.38E-03
Radishes	1.10E+05	1664	0.000637	0.0062	1.27E-01	6.01E-03
Radishes	1.10E+05	1664	0.000637	0.0062	1.72E-01	8.13E-03
Radishes	1.10E+05	1664	0.000637	0.0062	1.37E-01	6.47E-03
Red Potatoes	1.10E+05	1664	0.000637	0.0062	1.09E-01	5.13E-03
Red Potatoes	1.10E+05	1664	0.000637	0.0062	1.14E-01	5.40E-03
Rice	1.10E+05	1664	0.000637	0.0062	7.29E-02	3.44E-03
Rice	3.40E+05	1670	0.0045	0.0016	5.39E-01	1.58E-03
Rice	3.40E+05	1670	0.0045	0.0016	5.99E-01	1.75E-03
Spinach	1.10E+05	1664	0.000637	0.0062	4.26E-01	2.01E-02
Spinach	1.10E+05	1664	0.000637	0.0062	7.52E-01	3.55E-02
Spinach	1.10E+05	1664	0.000637	0.0062	8.78E-02	4.14E-03
Strawberries	3.40E+05	1670	0.0045	0.0016	1.00E+00	2.93E-03
Strawberries	1.10E+05	1664	0.000637	0.0062	1.05E-01	4.96E-03
Strawberries	3.40E+05	1670	0.0045	0.0016	1.04E+00	3.04E-03
Swiss Chard	3.40E+05	1670	0.0045	0.0016	2.01E+00	5.89E-03
Tangerine	3.40E+05	1670	0.0045	0.0016	1.27E+00	3.71E-03
Tangerine	1.10E+05	1664	0.000637	0.0062	1.06E-01	5.02E-03
Tomatoes	1.10E+05	1664	0.000637	0.0062	1.05E-01	4.97E-03
Tomatoes	3.40E+05	1670	0.0045	0.0016	9.28E-01	2.72E-03
Tomatoes	3.40E+05	1670	0.0045	0.0016	8.05E-01	2.36E-03
Turnip Greens	1.10E+05	1664	0.000637	0.0062	2.79E-01	1.32E-02
Turnip Greens	1.10E+05	1664	0.000637	0.0062	1.35E-01	6.39E-03
Turnip Greens	3.40E+05	1670	0.0045	0.0016	6.19E-01	1.81E-03

	Calibration Factors		Bkgnd Count		Minimum Det. Activity	
	Pb-210	**Ra-226**	**Pb-210**	**Ra-226**	**Pb-210**	**Ra-226**
Item	**(pCi/cps)**	**(pCi/cps)**	**(counts)**	**(counts)**	**(pCi/g)**	**(pCi/g)**
Turnip Root and Green	3.40E+05	1670	0.0045	0.0016	1.84E+00	5.39E-03
Turnip Roots	1.10E+05	1664	0.000637	0.0062	1.37E-01	6.49E-03
Turnip Roots	3.40E+05	1670	0.0045	0.0016	8.02E+02	2.35E+00
Watermelon	3.40E+05	1670	0.0045	0.0016	6.70E-01	1.96E-03
Watermelon	3.40E+05	1670	0.0045	0.0016	8.82E-01	2.58E-03
Yellow Corn	3.40E+05	1670	0.0045	0.0016	9.57E-01	2.80E-03
Yellow Corn	1.10E+05	1664	0.000637	0.0062	1.81E-01	8.54E-03
Yellow Corn	3.40E+05	1670	0.0045	0.0016	9.03E-01	2.65E-03
Yellow Squash	3.40E+05	1670	0.0045	0.0016	9.37E-01	2.74E-03
Yellow Squash	1.10E+05	1664	0.000637	0.0062	1.22E-01	5.75E-03
Yellow Squash	1.10E+05	1664	0.000637	0.0062	1.18E-01	5.56E-03
Zucchini	1.10E+05	1664	0.000637	0.0062	9.59E-02	4.53E-03
Zucchini	1.10E+05	1664	0.000637	0.0062	1.14E-01	5.39E-03
Zucchini	1.10E+05	1664	0.000637	0.0062	1.15E-01	5.44E-03
Brazil Nuts	1.10E+05	1664	0.000637	0.0062	1.18E-01	5.58E-03

	Actual		Reported		Averages	
	Pb-210	Ra-226	Pb-210	Ra-226	Pb-210	Ra-226
Item	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)
Beef	0.00E+00	0.00E+00	0.076	0.004	0.076	0.004
Beef Kidney	3.57E-01	2.02E-03	0.357	0.002	0.357	0.002
Black-Eyed Peas	0.000	0.000	0.482	0.001		
Black-Eyed Peas	0.000	0.000	0.910	0.003		
Black-Eyed Peas	0.000	0.000	0.090	0.004	0.494	0.003
Brazil Shells	0.000	0.000	1.021	0.003	1.021	0.003
Broccoli	0.000	0.000	0.159	0.008		
Broccoli	0.000	0.000	1.251	0.004		
Broccoli	0.000	0.000	1.077	0.003	0.829	0.005
Cabbage	0.000	0.000	1.659	0.005		
Cabbage	0.000	0.000	0.237	0.011		
Cabbage	0.677	0.003	0.677	0.003	0.858	0.006
Carrots	0.000	0.000	1.217	0.004		
Carrots	0.330	0.002	0.330	0.002		
Carrots	0.000	0.000	0.116	0.005	0.555	0.004
Cauliflower	1.257	0.005	1.257	0.005		
Cauliflower	0.000	0.000	2.260	0.007		
Cauliflower	0.000	0.000	0.882	0.003	1.466	0.005
Collard Greens	0.986	0.009	0.986	0.009		
Collard Greens	0.000	0.000	0.571	0.002		
Collard Greens	0.000	0.000	2.559	0.007	1.372	0.006
Corn	0.000	0.000	1.204	0.004		
Corn	0.000	0.000	0.213	0.010		
Corn	0.000	0.000	0.102	0.005	0.506	0.006
Cucumber	136.830	0.020	136.830	0.020		
Cucumber	3.339	0.003	3.339	0.003		
Cucumber	0.000	0.000	1.078	0.003	47.082	0.009
Eggplant	0.000	0.000	1.464	0.004		
Eggplant	0.000	0.000	0.126	0.006		
Eggplant	0.000	0.000	2.683	0.008	1.425	0.006
Grapefruit	0.000	0.000	0.095	0.004		
Grapefruit	0.000	0.000	0.092	0.004		
Grapefruit	0.000	0.000	0.101	0.005	0.096	0.005

	Actual		Reported		Averages	
	Pb-210	Ra-226	Pb-210	Ra-226	Pb-210	Ra-226
Item	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)
Green Beans	6.489	0.013	6.489	0.013		
Green Beans	3.987	0.003	3.987	0.003		
Green Beans	0.000	0.000	1.035	0.003	3.837	0.007
Green Onions	0.000	0.000	0.437	0.021		
Green Onions	0.000	0.000	0.329	0.016		
Green Onions	0.000	0.000	1.791	0.005	0.852	0.014
Green Peppers	0.000	0.000	1.088	0.003		
Green Peppers	0.000	0.000	0.102	0.005		
Green Peppers	0.000	0.000	0.102	0.005	0.430583	0.004275
Irish Creamer Potatoes	0.000	0.000	0.120	0.006	0.120	0.006
Lemons	0.000	0.000	0.119	0.006		
Lemons	0.000	0.000	1.008	0.003		
Lemons	0.000	0.000	0.114	0.005	0.414	0.005
Lettuce	0.000	0.000	1.420	0.004		
Lettuce	0.000	0.000	1.197	0.004		
Lettuce	0.000	0.000	1.094	0.003	1.237	0.004
Lima Beans	1.650	0.000	1.650	0.003		
Lima Beans	0.324	0.003	0.324	0.003		
Lima Beans	0.000	0.000	0.914	0.003	0.963	0.003
Mustard Greens	1.622	0.017	1.622	0.017	1.622	0.017
Okra	0.000	0.000	1.934	0.006		
Okra	0.000	0.000	1.000	0.003		
Okra	0.281	0.001	0.281	0.001	1.072	0.003
Onions	0.000	0.000	0.926	0.003		
Onions	0.000	0.000	0.744	0.002		
Onions	0.000	0.000	0.128	0.006	0.599	0.004
Oranges	0.000	0.000	0.695	0.002		
Oranges	1.239	0.002	1.239	0.002		
Oranges	0.000	0.000	0.112	0.005	0.682064	0.003214
Parsley	0.000	0.000	0.531	0.025		
Parsley	0.000	0.000	19.614	0.057		
Parsley	0.000	0.000	1.990	0.006	7.378	0.029

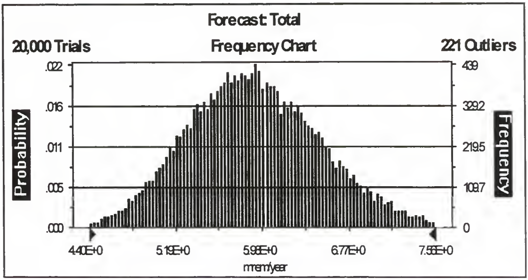
	Actual		Reported		Averages	
	Pb-210	Ra-226	Pb-210	Ra-226	Pb-210	Ra-226
Item	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)
Peas	0.000	0.000	1.180	0.003		
Peas	0.259	0.004	0.259	0.004		
Peas	0.000	0.000	1.023	0.003	0.821	0.003
Pole Beans	0.000	0.000	1.307	0.004		
Pole Beans	0.000	0.000	0.102	0.005	0.704476	0.004326
Potato	0.000	0.000	0.780	0.002		
Potato	0.000	0.000	0.863	0.003		
Potato	0.000	0.000	0.895	0.003	0.846	0.002
Purple Hull Peas	0.000	0.000	0.097	0.005		
Purple Hull Peas	0.000	0.000	0.811	0.002	0.453905	0.003469
Radishes	0.184	0.004	0.184	0.004		
Radishes	1.285	0.006	1.285	0.006		
Radishes	0.270	0.001	0.270	0.001	0.580	0.004
Red Potatoes	0.000	0.000	0.109	0.005		
Red Potatoes	0.321	0.002	0.321	0.002	0.214874	0.00335
Rice	0.000	0.000	0.073	0.003		
Rice	1.290	0.002	1.290	0.002		
Rice	0.000	0.000	0.599	0.002	0.653919	0.002407
Spinach	0.000	0.000	0.426	0.020		
Spinach	0.000	0.000	0.752	0.036		
Spinach	0.000	0.000	0.088	0.004	0.422	0.020
Strawberries	0.000	0.000	1.002	0.003		
Strawberries	0.000	0.000	0.105	0.005		
Strawberries	0.000	0.000	1.038	0.003	0.715	0.004
Swiss Chard	0.000	0.000	2.010	0.006	2.010	0.006
Tangerine	0.000	0.000	1.265	0.004		
Tangerine	0.000	0.000	0.106	0.005	0.685906	0.004364
Tomatoes	0.000	0.000	0.105	0.005		
Tomatoes	0.000	0.000	0.928	0.003		
Tomatoes	1.999	0.002	1.999	0.002	1.011	0.003
Turnip Greens	1.296	0.009	1.296	0.009		
Turnip Greens	0.000	0.000	0.135	0.006		
Turnip Greens	1.393	0.002	1.393	0.002	0.941	0.006

	Actual		Reported		Averages	
	Pb-210	Ra-226	Pb-210	Ra-226	Pb-210	Ra-226
Item	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)	(pCi/g)
Turnip Root and Green	0.000	0.000	1.841	0.005	1.841	0.005
Turnip Roots	0.491	0.005	0.491	0.005		
Turnip Roots	0.000	0.000	801.988	2.349	0.941	0.006
Watermelon	0.000	0.000	0.670	0.002		
Watermelon	0.000	0.000	0.882	0.003	0.775771	0.002272
Yellow Corn	0.000	0.000	0.957	0.003		
Yellow Corn	0.000	0.000	0.181	0.009		
Yellow Corn	0.000	0.000	0.903	0.003	0.680	0.005
Yellow Squash	0.000	0.000	0.937	0.003		
Yellow Squash	0.784	0.004	0.784	0.004		
Yellow Squash	0.000	0.000	0.118	0.006	0.613	0.004
Zucchini	0.000	0.000	0.096	0.005		
Zucchini	0.000	0.000	0.114	0.005		
Zucchini	0.000	0.000	0.115	0.005	0.108	0.005
Brazil Nuts	1.324	0.007	1.324	0.007	1.324	0.007

APPENDIX B
CRYSTAL BALL OUTPUT DATA

1990 FIPR Data
Ra-226

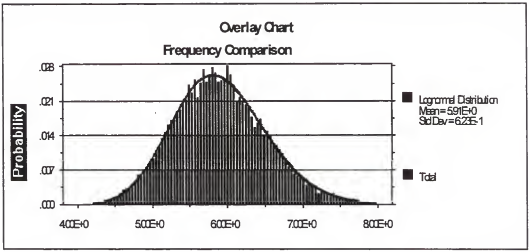
Set 1
Crystal Ball Output
Frequency Chart

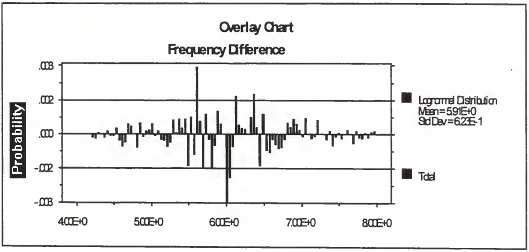


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		5.92E+00
Median		5.89E+00
Mode	---	
Standard Deviation		6.23E-01
Variance		3.88E-01
Skewness		0.3
Kurtosis		3.17
Coeff. of Variability		0.11
Range Minimum		3.92E+00
Range Maximum		8.74E+00
Range Width		4.81E+00
Mean Std. Error		4.41E-03

1990 FIPR Data
Ra-226

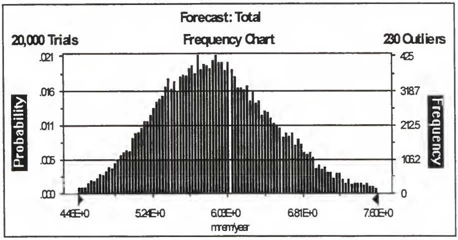
Set 1
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Ra-226

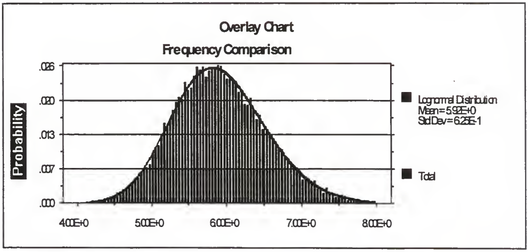
Set 2
Crystal Ball Output
Frequency Chart

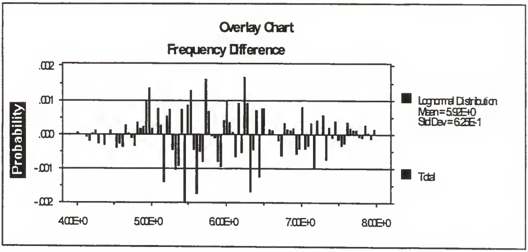


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		5.91E+00
Median		5.88E+00
Mode	---	
Standard Deviation		6.30E-01
Variance		3.97E-01
Skewness		0.32
Kurtosis		3.13
Coeff. of Variability		0.11
Range Minimum		3.98E+00
Range Maximum		9.14E+00
Range Width		5.16E+00
Mean Std. Error		4.46E-03

1990 FIPR Data
Ra-226

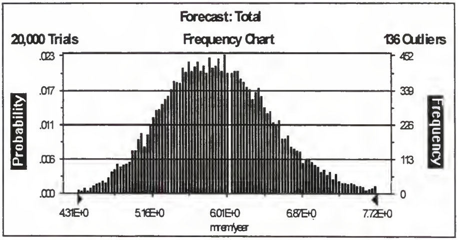
Set 2
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Ra-226

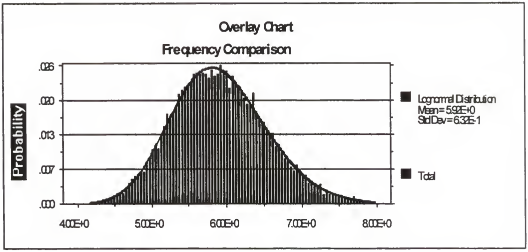
Set 3
Crystal Ball Output
Frequency Chart

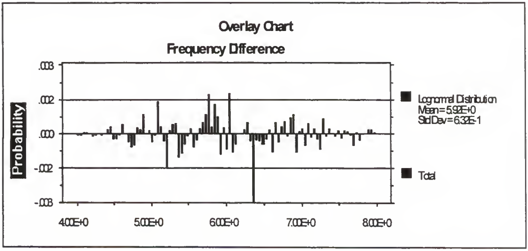


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		5.92E+00
Median		5.89E+00
Mode	---	
Standard Deviation		6.31E-01
Variance		3.99E-01
Skewness		0.3
Kurtosis		3.15
Coeff. of Variability		0.11
Range Minimum		3.79E+00
Range Maximum		8.89E+00
Range Width		5.10E+00
Mean Std. Error		4.46E-03

1990 FIPR Data
Ra-226

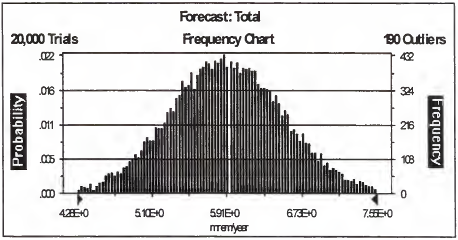
Set 3
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Ra-226

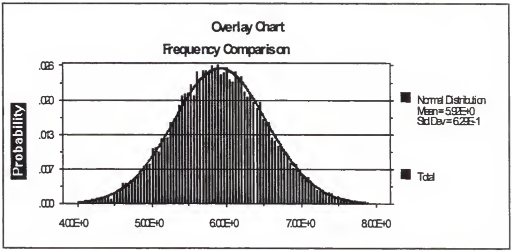
Set 4
Crystal Ball Output
Frequency Chart

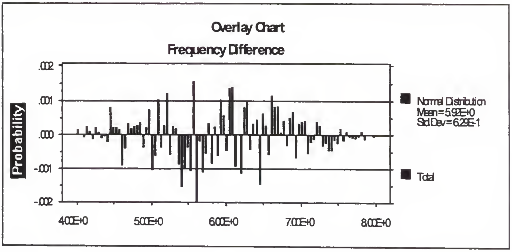


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		5.92E+00
Median		5.91E+00
Mode	---	
Standard Deviation		6.29E-01
Variance		3.95E-01
Skewness		0.06
Kurtosis		3.04
Coeff. of Variability		0.11
Range Minimum		3.72E+00
Range Maximum		8.63E+00
Range Width		4.91E+00
Mean Std. Error		4.45E-03

1990 FIPR Data
Ra-226

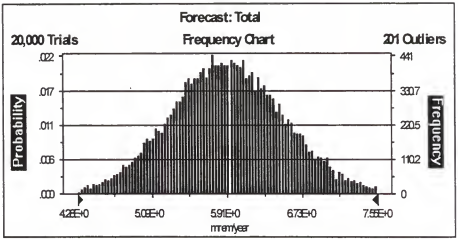
Set 4
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Ra-226

Set 5
Crystal Ball Output
Distributions Fitting Chart

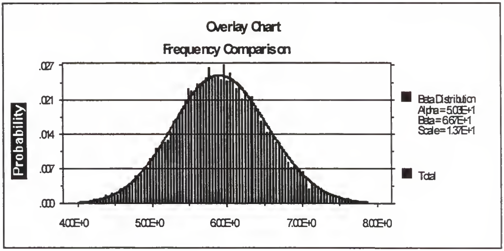


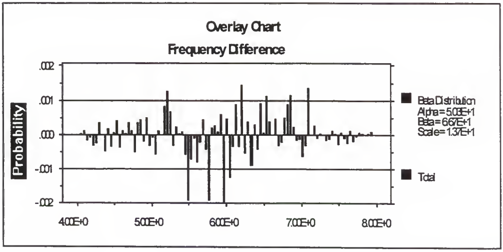
Forecast: Total

Statistic	Value
Trials	20000
Mean	5.92E+00
Median	5.91E+00
Mode	---
Standard Deviation	6.27E-01
Variance	3.93E-01
Skewness	0.05
Kurtosis	3.04
Coeff. of Variability	0.11
Range Minimum	3.50E+00
Range Maximum	8.63E+00
Range Width	5.12E+00
Mean Std. Error	4.44E-03

1990 FIPR Data
Ra-226

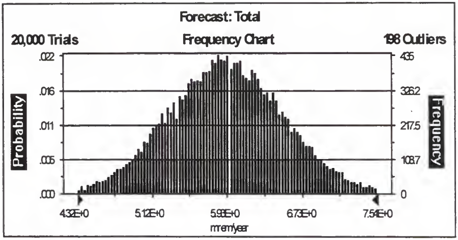
Set 5
Crystal Ball Output
Frequency Chart





1990 FIPR Data
Ra-226

Set 6
Crystal Ball Output
Distributions Fitting Chart

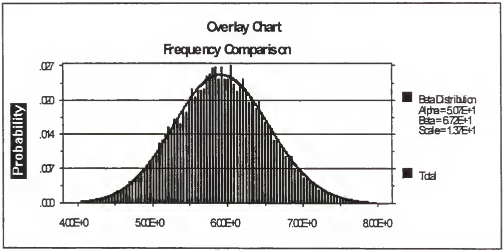


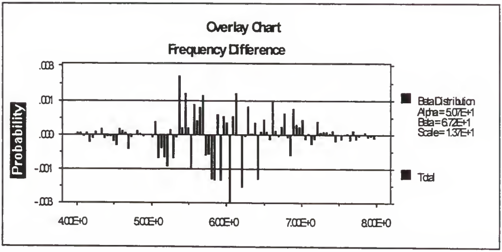
Forecast: Total

Statistic	Value
Trials	20000
Mean	5.92E+00
Median	5.92E+00
Mode	---
Standard Deviation	6.26E-01
Variance	3.91E-01
Skewness	0.05
Kurtosis	2.97
Coeff. of Variability	0.11
Range Minimum	3.51E+00
Range Maximum	8.13E+00
Range Width	4.62E+00
Mean Std. Error	4.42E-03

1990 FIPR Data
Ra-226

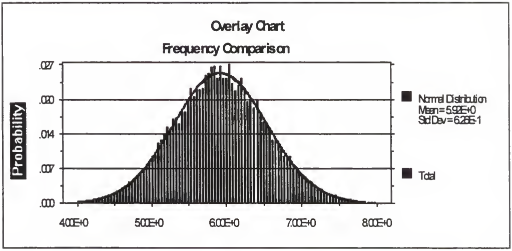
Set 6
Crystal Ball Output
Distributions Fitting Chart

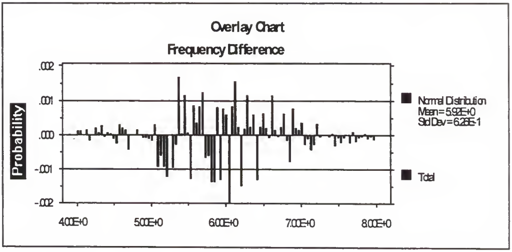




1990 FIPR Data
Ra-226

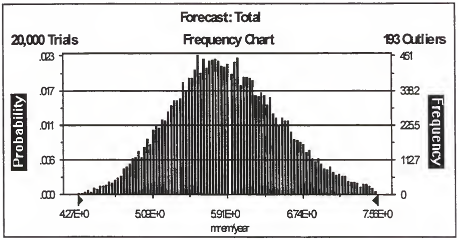
Set 6
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Ra-226

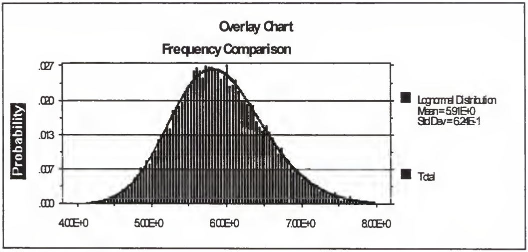
Set 7
Crystal Ball Output
Frequency Chart

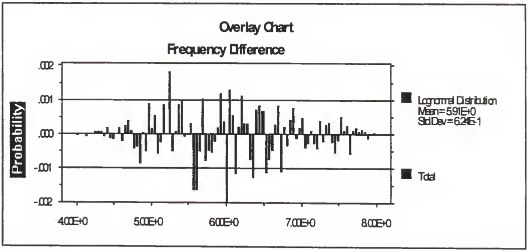


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		5.91E+00
Median		5.88E+00
Mode	---	
Standard Deviation		6.24E-01
Variance		3.89E-01
Skewness		0.32
Kurtosis		3.3
Coeff. of Variability		0.11
Range Minimum		3.89E+00
Range Maximum		1.01E+01
Range Width		6.23E+00
Mean Std. Error		4.41E-03

1990 FIPR Data
Ra-226

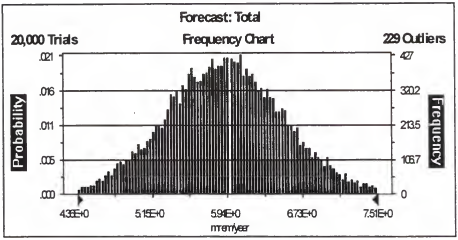
Set 7
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Ra-226

Set 8
Crystal Ball Output
Frequency Chart

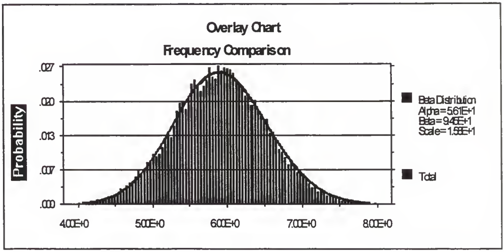


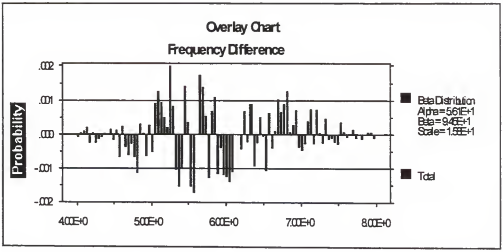
Forecast: Total

Statistic	Value
Trials	20000
Mean	5.92E+00
Median	5.92E+00
Mode	---
Standard Deviation	6.24E-01
Variance	3.89E-01
Skewness	0.08
Kurtosis	3.04
Coeff. of Variability	0.11
Range Minimum	3.67E+00
Range Maximum	8.95E+00
Range Width	5.28E+00
Mean Std. Error	4.41E-03

1990 FIPR Data
Ra-226

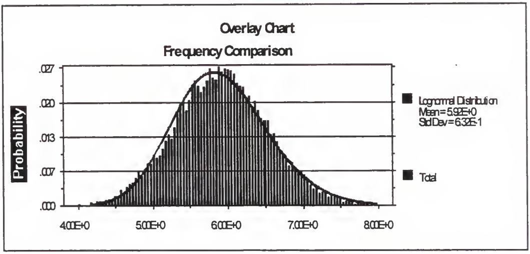
Set 8
Crystal Ball Output
Distributions Fitting Chart





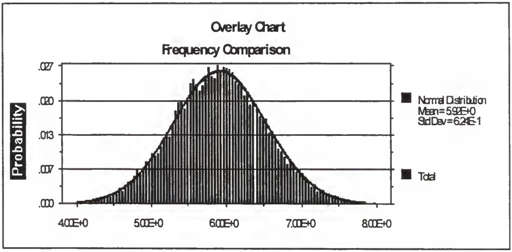
1990 FIPR Data
Ra-226

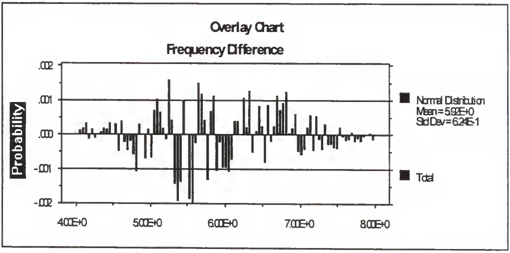
Set 8
Crystal Ball Output
Distributions Fitting Chart



1990 FIPR Data
Ra-226

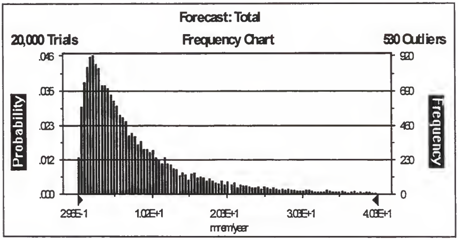
Set 8
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Ra-226

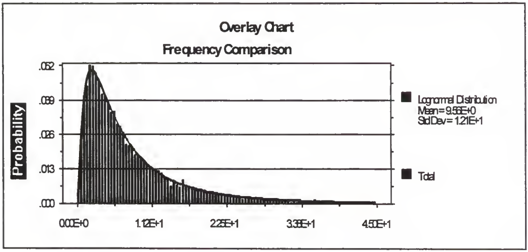
Set 9
Crystal Ball Output
Frequency Chart

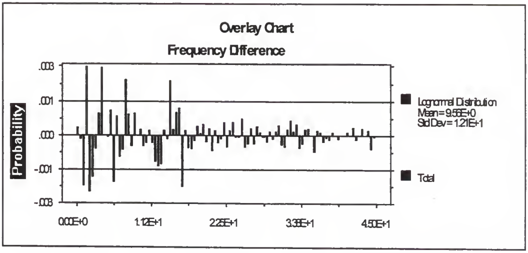


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		9.58E+00
Median		5.91E+00
Mode	---	
Standard Deviation		1.20E+01
Variance		1.46E+02
Skewness		5.08
Kurtosis		53.59
Coeff. of Variability		1.26
Range Minimum		1.59E-01
Range Maximum		2.71E+02
Range Width		2.70E+02
Mean Std. Error		8.55E-02

1990 FIPR Data
Ra-226

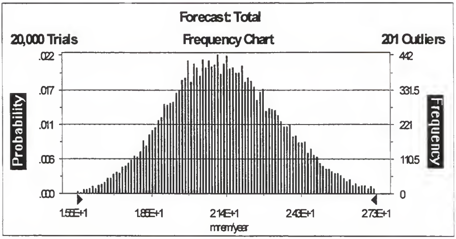
Set 9
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Pb-210

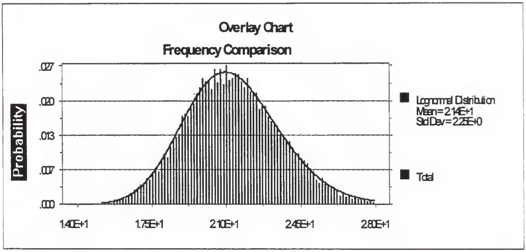
Set 1
Crystal Ball Output
Frequency Chart

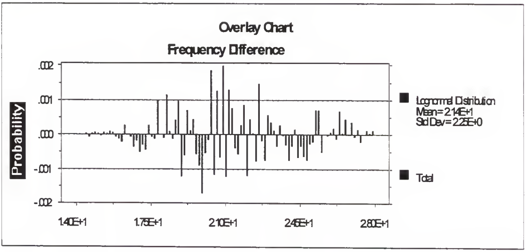


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		2.14E+01
Median		2.13E+01
Mode	---	
Standard Deviation		2.25E+00
Variance		5.06E+00
Skewness		0.32
Kurtosis		3.18
Coeff. of Variability		0.11
Range Minimum		1.45E+01
Range Maximum		3.22E+01
Range Width		1.76E+01
Mean Std. Error		1.59E-02

1990 FIPR Data
Pb-210

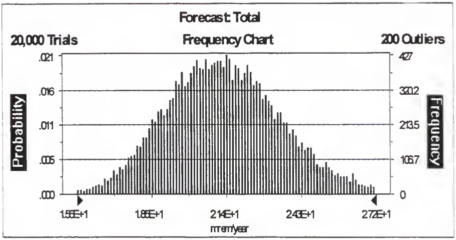
Set 1
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Pb-210

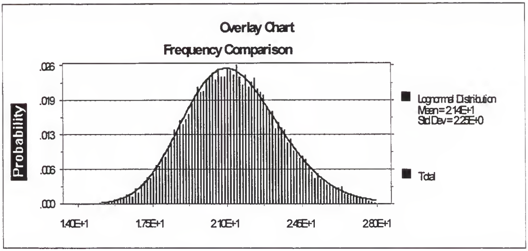
Set 2
Crystal Ball Output
Frequency Chart

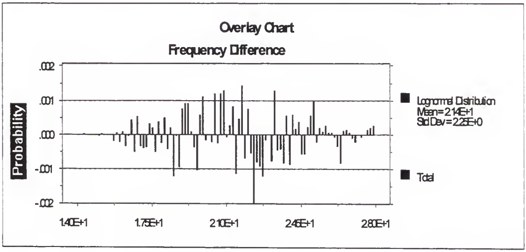


Forecast: Total	
Statistic	Value
Trials	20000
Mean	2.14E+01
Median	2.13E+01
Mode	---
Standard Deviation	2.25E+00
Variance	5.06E+00
Skewness	0.29
Kurtosis	3.1
Coeff. of Variability	0.11
Range Minimum	1.42E+01
Range Maximum	3.24E+01
Range Width	1.82E+01
Mean Std. Error	1.59E-02

1990 FIPR Data
Pb-210

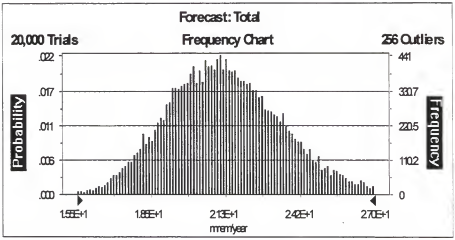
Set 2
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Pb-210

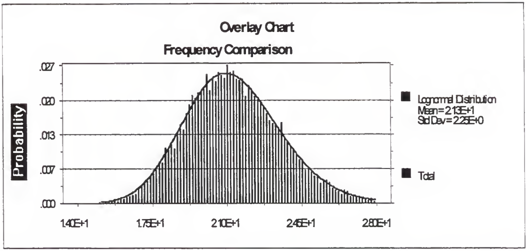
Set 3
Crystal Ball Output
Frequency Chart

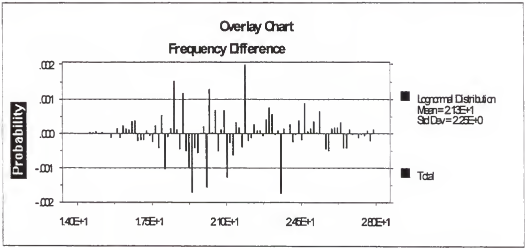


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		2.13E+01
Median		2.12E+01
Mode	---	
Standard Deviation		2.26E+00
Variance		5.09E+00
Skewness		0.37
Kurtosis		3.27
Coeff. of Variability		0.11
Range Minimum		1.38E+01
Range Maximum		3.35E+01
Range Width		1.96E+01
Mean Std. Error		1.59E-02

1990 FIPR Data
Pb-210

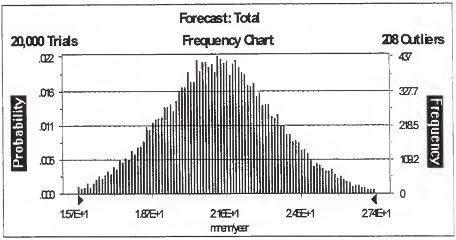
Set 3
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Pb-210

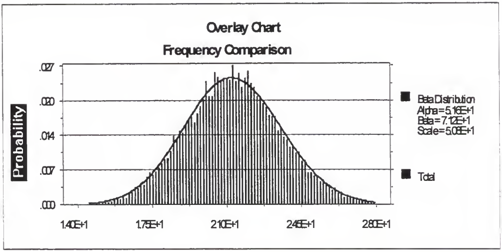
Set 4
Crystal Ball Output
Frequency Chart

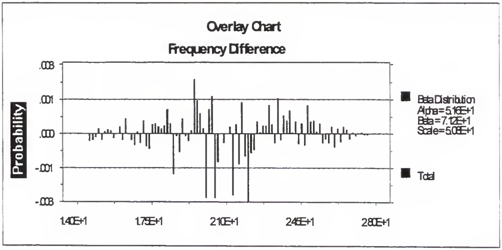


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		2.13E+01
Median		2.13E+01
Mode	---	
Standard Deviation		2.25E+00
Variance		5.08E+00
Skewness		0.06
Kurtosis		3.04
Coeff. of Variability		0.11
Range Minimum		1.21E+01
Range Maximum		3.05E+01
Range Width		1.84E+01
Mean Std. Error		1.59E-02

1990 FIPR Data
Pb-210

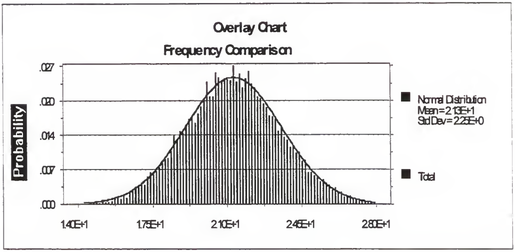
Set 4
Crystal Ball Output
Distributions Fitting Chart

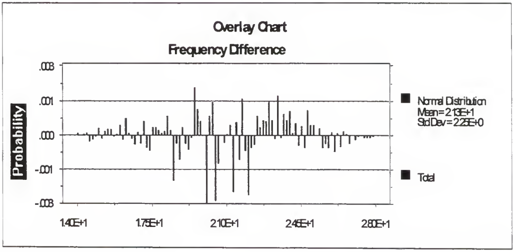




1990 FIPR Data
Pb-210

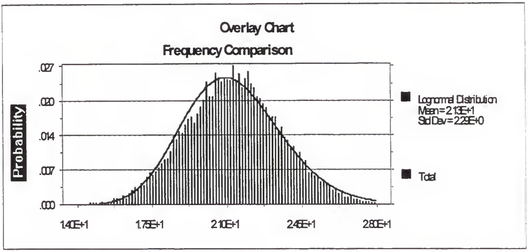
Set 4
Crystal Ball Output
Distributions Fitting Chart

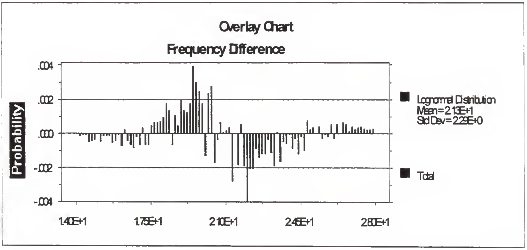




1990 FIPR Data
Pb-210

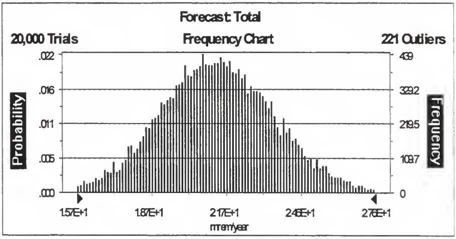
Set 4
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Pb-210

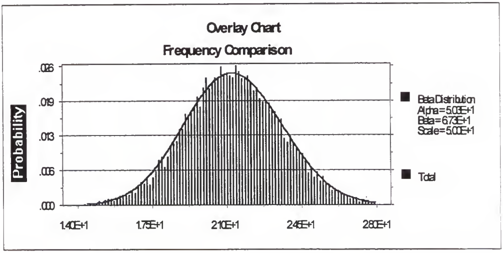
Set 5
Crystal Ball Output
Frequency Chart

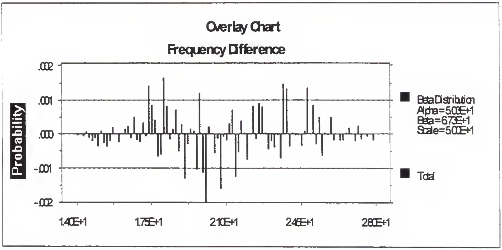


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		2.14E+01
Median		2.13E+01
Mode	---	
Standard Deviation		2.27E+00
Variance		5.15E+00
Skewness		0.05
Kurtosis		3.06
Coeff. of Variability		0.11
Range Minimum		1.22E+01
Range Maximum		3.12E+01
Range Width		1.90E+01
Mean Std. Error		1.60E-02

1990 FIPR Data
Pb-210

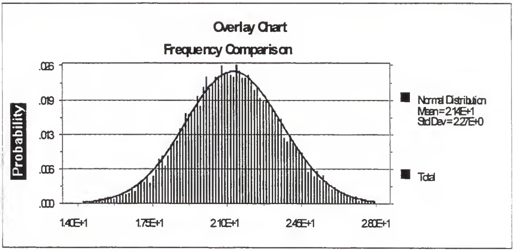
Set 5
Crystal Ball Output
Distributions Fitting Chart

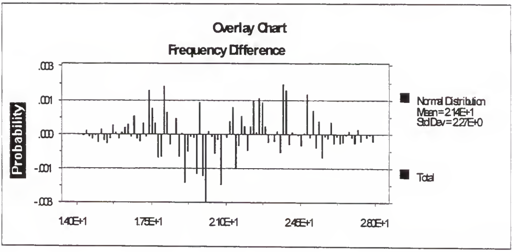




1990 FIPR Data
Pb-210

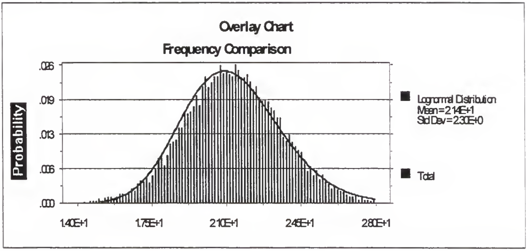
Set 5
Crystal Ball Output
Distributions Fitting Chart

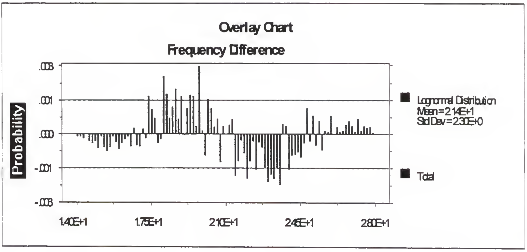




1990 FIPR Data
Pb-210

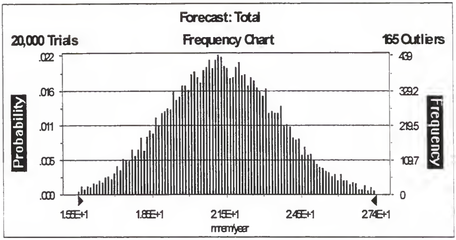
Set 5
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Pb-210

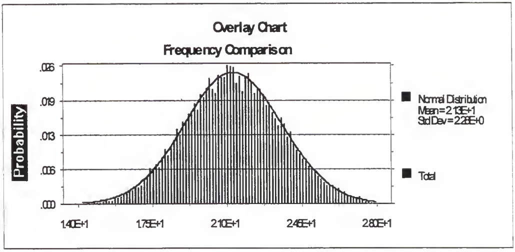
Set 6
Crystal Ball Output
Frequency Chart

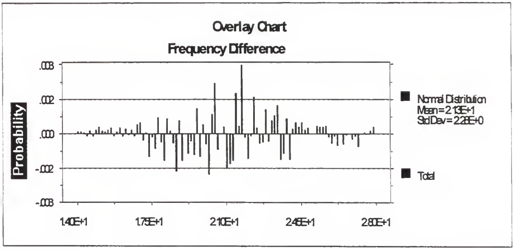


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		2.13E+01
Median		2.13E+01
Mode	---	
Standard Deviation		2.28E+00
Variance		5.18E+00
Skewness		0.08
Kurtosis		2.99
Coeff. of Variability		0.11
Range Minimum		1.24E+01
Range Maximum		3.14E+01
Range Width		1.90E+01
Mean Std. Error		1.61E-02

1990 FIPR Data
Pb-210

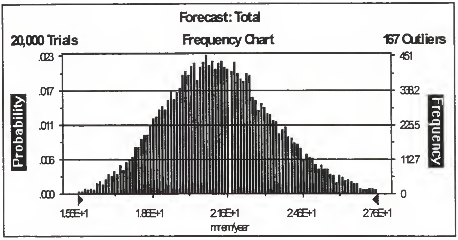
Set 6
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Pb-210

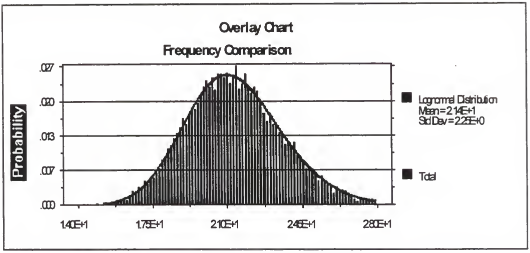
Set 7
Crystal Ball Output
Frequency Chart

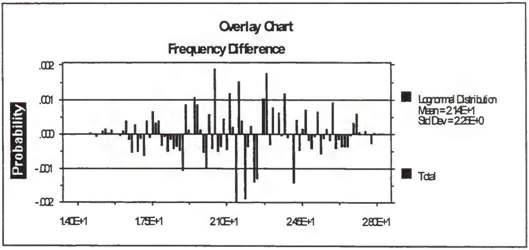


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		2.14E+01
Median		2.13E+01
Mode	---	
Standard Deviation		2.26E+00
Variance		5.09E+00
Skewness		0.33
Kurtosis		3.18
Coeff. of Variability		0.11
Range Minimum		1.36E+01
Range Maximum		3.18E+01
Range Width		1.82E+01
Mean Std. Error		1.59E-02

1990 FIPR Data
Pb-210

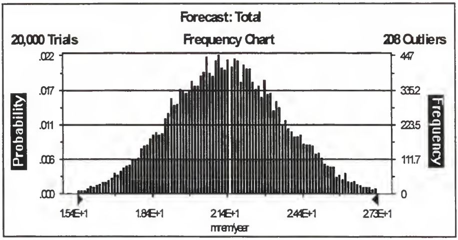
Set 7
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Pb-210

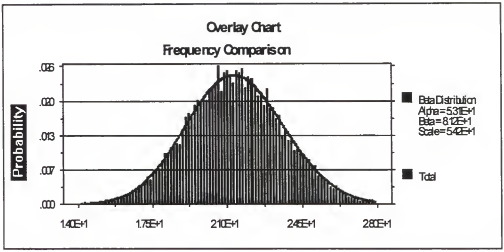
Set 8
Crystal Ball Output
Frequency Chart

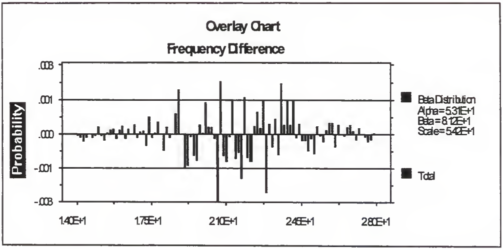


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		2.14E+01
Median		2.14E+01
Mode	---	
Standard Deviation		2.28E+00
Variance		5.18E+00
Skewness		0.07
Kurtosis		3.05
Coeff. of Variability		0.11
Range Minimum		1.20E+01
Range Maximum		3.02E+01
Range Width		1.81E+01
Mean Std. Error		1.61E-02

1990 FIPR Data
Pb-210

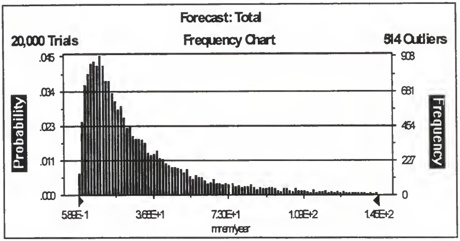
Set 8
Crystal Ball Output
Distributions Fitting Chart





1990 FIPR Data
Pb-210

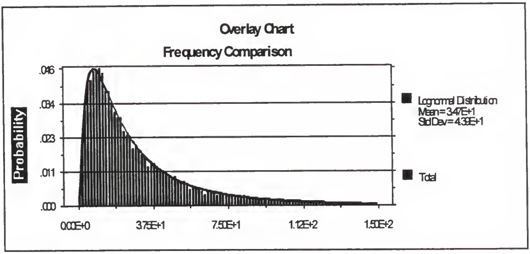
Set 9
Crystal Ball Output
Frequency Chart

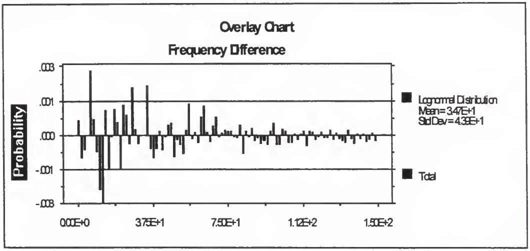


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		3.47E+01
Median		2.14E+01
Mode	---	
Standard Deviation		4.35E+01
Variance		1.89E+03
Skewness		5.18
Kurtosis		56.66
Coeff. of Variability		1.25
Range Minimum		3.96E-01
Range Maximum		9.65E+02
Range Width		9.65E+02
Mean Std. Error		3.08E-01

90 FIPR Data
Pb-210

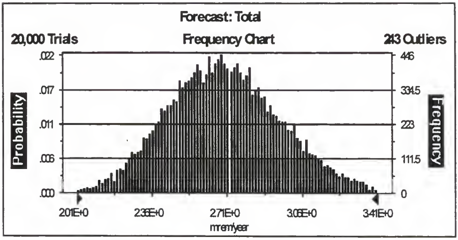
Set 9
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Ra-226

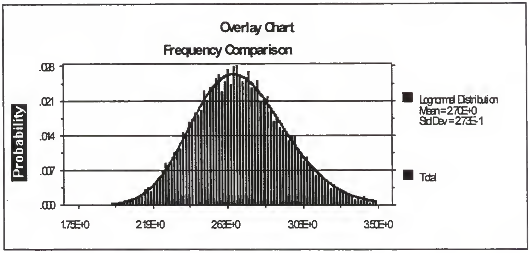
Set 1
Crystal Ball Output
Frequency Chart

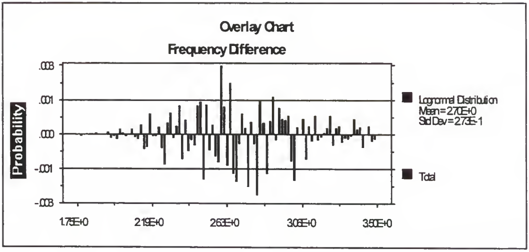


Forecast: Total	
Statistic	Value
Trials	20000
Mean	2.70E+00
Median	2.69E+00
Mode	---
Standard Deviation	2.73E-01
Variance	7.44E-02
Skewness	0.31
Kurtosis	3.22
Coeff. of Variability	0.1
Range Minimum	1.78E+00
Range Maximum	4.06E+00
Range Width	2.27E+00
Mean Std. Error	1.93E-03

Grocery Store Data
Ra-226

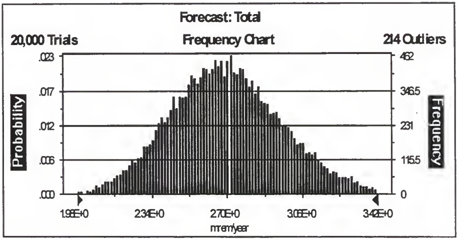
Set 1
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Ra-226

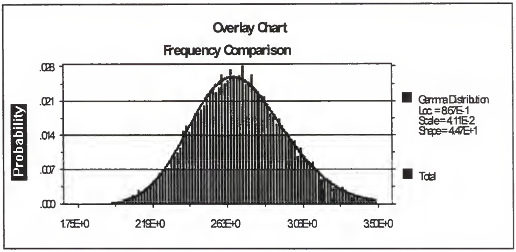
Set 2
Crystal Ball Output
Frequency Chart



Forecast: Total	
Statistic	Value
Trials	20000
Mean	2.70E+00
Median	2.69E+00
Mode	---
Standard Deviation	2.75E-01
Variance	7.56E-02
Skewness	0.32
Kurtosis	3.29
Coeff. of Variability	0.1
Range Minimum	1.88E+00
Range Maximum	4.13E+00
Range Width	2.25E+00
Mean Std. Error	1.94E-03

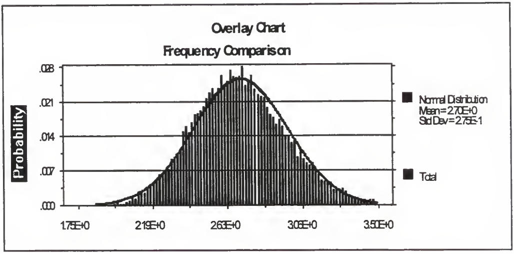
Grocery Store Data
Ra-226

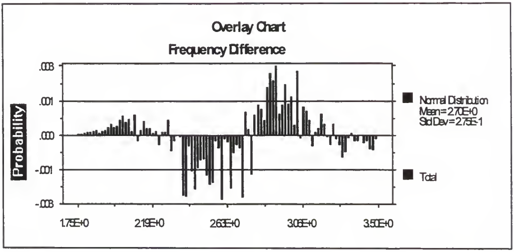
Set 2
Crystal Ball Output
Distributions Fitting Chart



Grocery Store Data
Ra-226

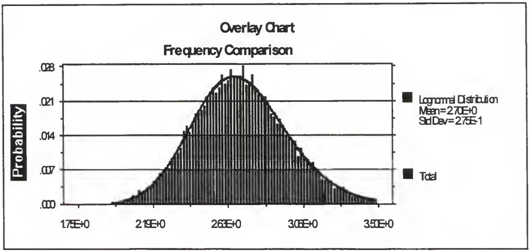
Set 2
Crystal Ball Output
Distributions Fitting Chart

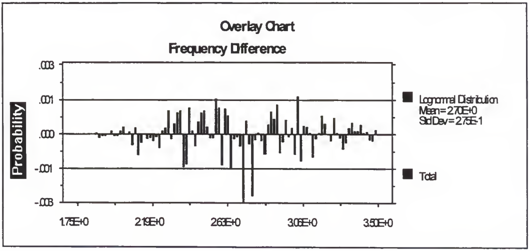




Grocery Store Data
Ra-226

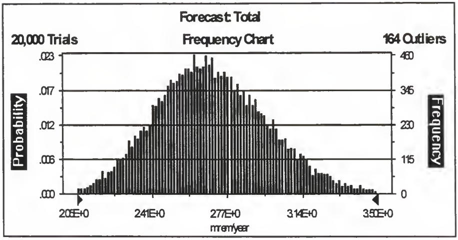
Set 2
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Ra-226

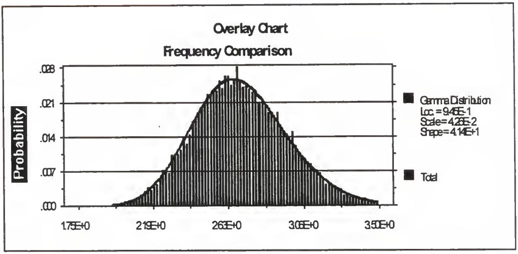
Set 3
Crystal Ball Output
Frequency Chart

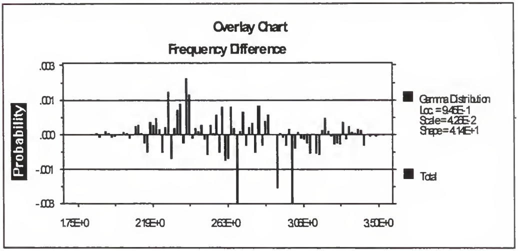


Forecast: Total	
Statistic	Value
Trials	20000
Mean	2.70E+00
Median	2.69E+00
Mode	---
Standard Deviation	2.74E-01
Variance	7.49E-02
Skewness	0.31
Kurtosis	3.15
Coeff. of Variability	0.1
Range Minimum	1.87E+00
Range Maximum	3.93E+00
Range Width	2.06E+00
Mean Std. Error	1.94E-03

Grocery Store Data
Ra-226

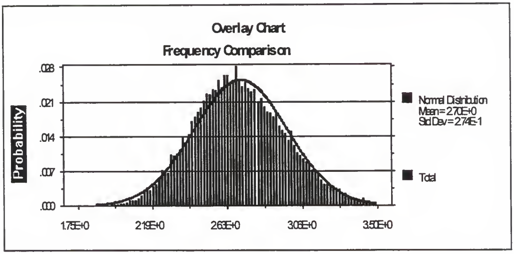
Set 3
Crystal Ball Output
Distributions Fitting Chart

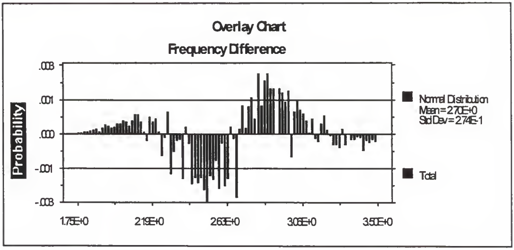




Grocery Store Data
Ra-226

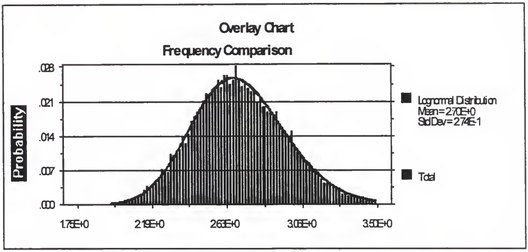
Set 3
Crystal Ball Output
Distributions Fitting Chart

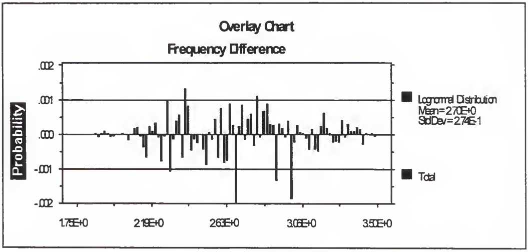




Grocery Store Data
Ra-226

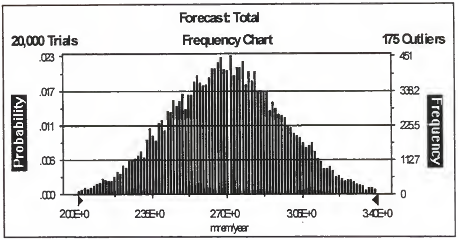
Set 3
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Ra-226

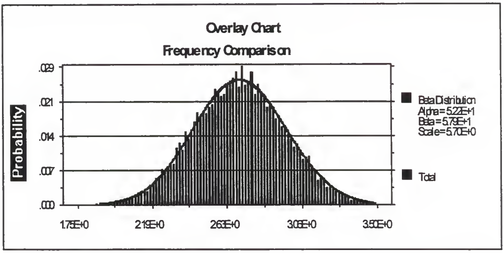
Set 4
Crystal Ball Output
Frequency Chart

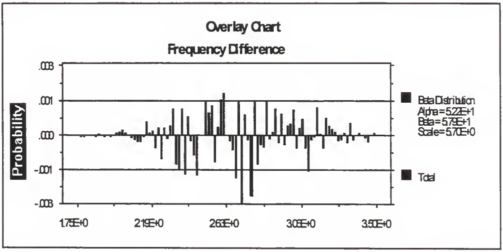


Forecast: Total	
Statistic	Value
Trials	20000
Mean	2.70E+00
Median	2.70E+00
Mode	---
Standard Deviation	2.70E-01
Variance	7.28E-02
Skewness	0.02
Kurtosis	2.95
Coeff. of Variability	0.1
Range Minimum	1.62E+00
Range Maximum	3.71E+00
Range Width	2.10E+00
Mean Std. Error	1.91E-03

Grocery Store Data
Ra-226

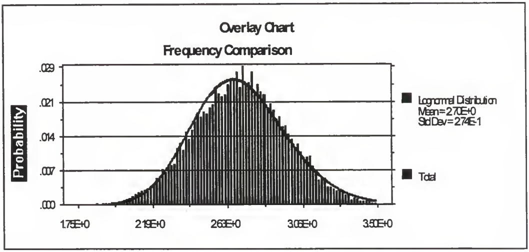
Set 4
Crystal Ball Output
Distributions Fitting Chart

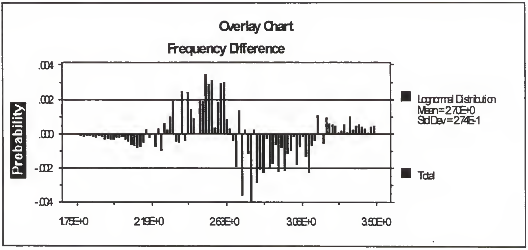




Grocery Store Data
Ra-226

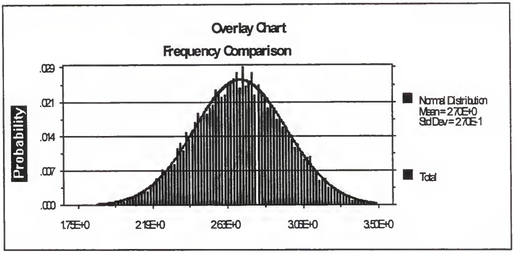
Set 4
Crystal Ball Output
Distributions Fitting Chart

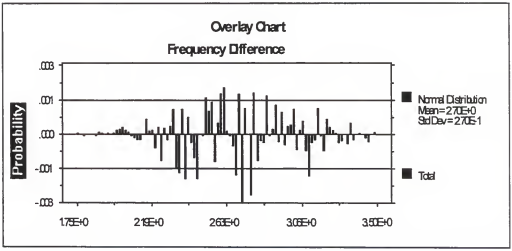




Grocery Store Data
Ra-226

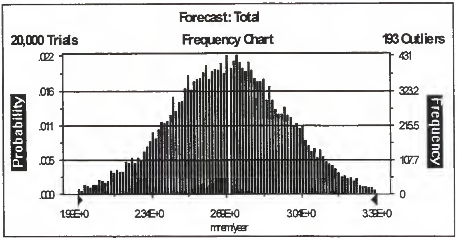
Set 4
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Ra-226

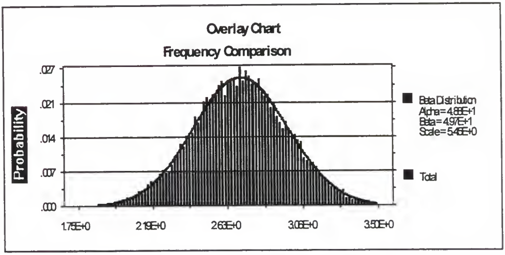
Set 5
Crystal Ball Output
Frequency Chart

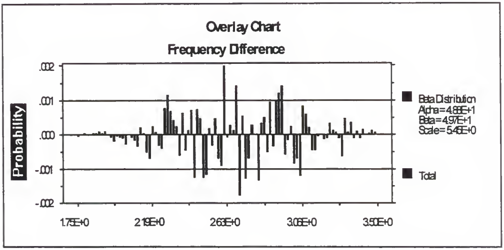


Forecast: Total	
Statistic	Value
Trials	20000
Mean	2.70E+00
Median	2.70E+00
Mode	---
Standard Deviation	2.73E-01
Variance	7.47E-02
Skewness	0
Kurtosis	2.95
Coeff. of Variability	0.1
Range Minimum	1.57E+00
Range Maximum	3.77E+00
Range Width	2.21E+00
Mean Std. Error	1.93E-03

Grocery Store Data
Ra-226

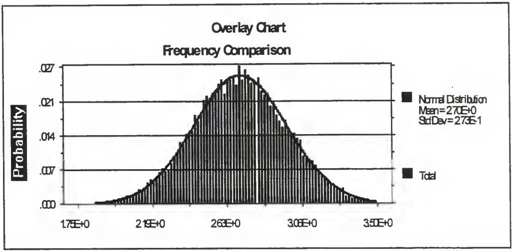
Set 5
Crystal Ball Output
Distributions Fitting Chart

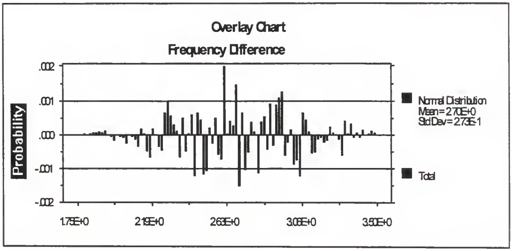




Grocery Store Data
Ra-226

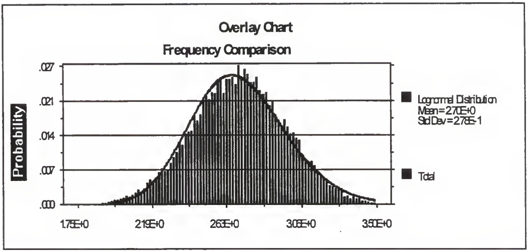
Set 5
Crystal Ball Output
Distributions Fitting Chart

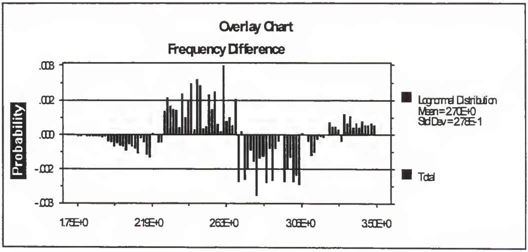




Grocery Store Data
Ra-226

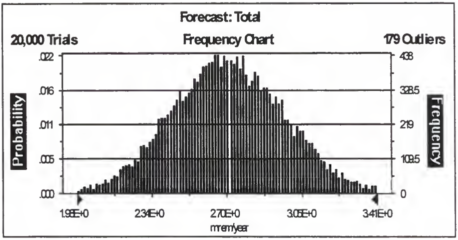
Set 5
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Ra-226

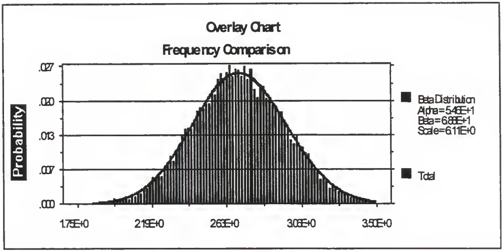
Set 6
Crystal Ball Output
Frequency Chart

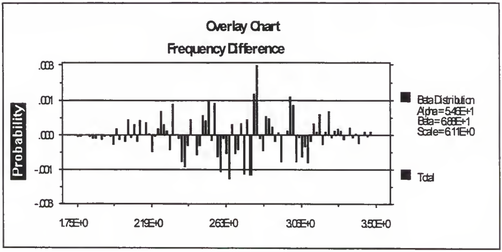


Forecast: Total	
Statistic	Value
Trials	20000
Mean	2.70E+00
Median	2.70E+00
Mode	---
Standard Deviation	2.72E-01
Variance	7.40E-02
Skewness	0.04
Kurtosis	3.03
Coeff. of Variability	0.1
Range Minimum	1.68E+00
Range Maximum	3.84E+00
Range Width	2.16E+00
Mean Std. Error	1.92E-03

Grocery Store Data
Ra-226

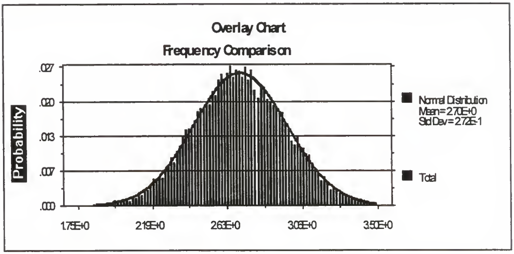
Set 6
Crystal Ball Output
Distributions Fitting Chart

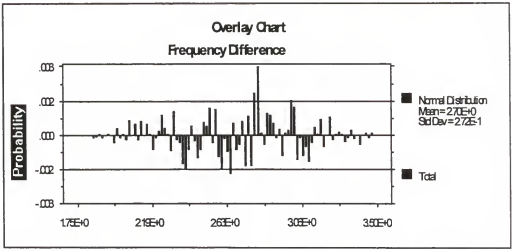




Grocery Store Data
Ra-226

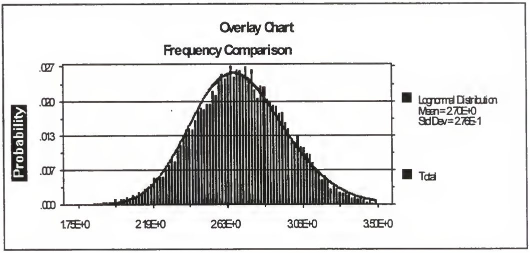
Set 6
Crystal Ball Output
Distributions Fitting Chart

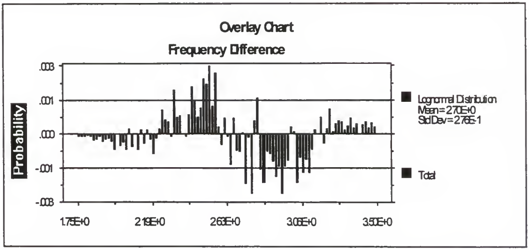




Grocery Store Data
Ra-226

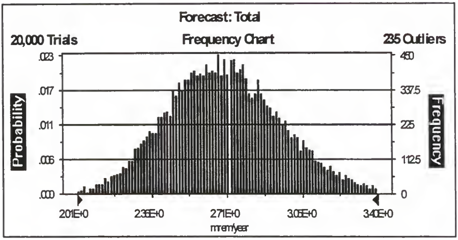
Set 6
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Ra-226

Set 7
Crystal Ball Output
Frequency Chart

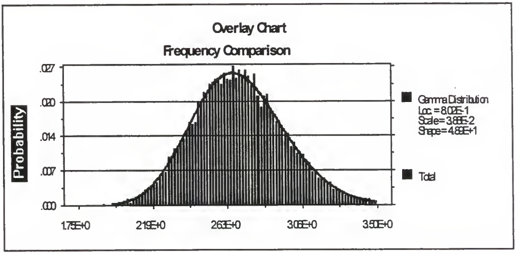


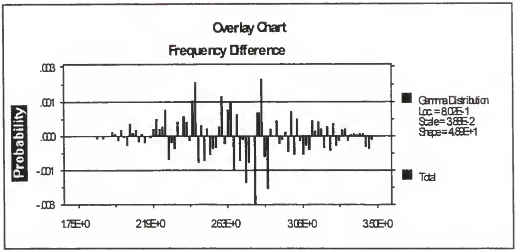
Forecast: Total

Statistic	Value
Trials	20000
Mean	2.70E+00
Median	2.69E+00
Mode	---
Standard Deviation	2.71E-01
Variance	7.36E-02
Skewness	0.3
Kurtosis	3.21
Coeff. of Variability	0.1
Range Minimum	1.66E+00
Range Maximum	4.11E+00
Range Width	2.45E+00
Mean Std. Error	1.92E-03

Grocery Store Data
Ra-226

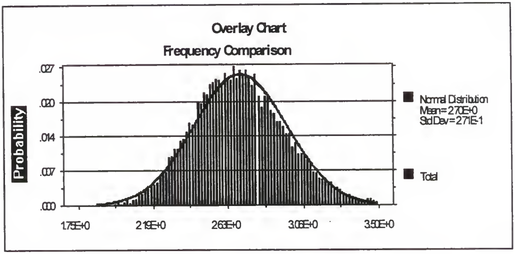
Set 7
Crystal Ball Output
Distributions Fitting Chart

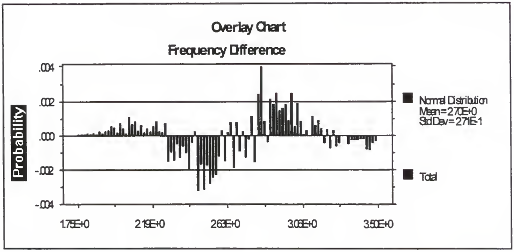




Grocery Store Data
Ra-226

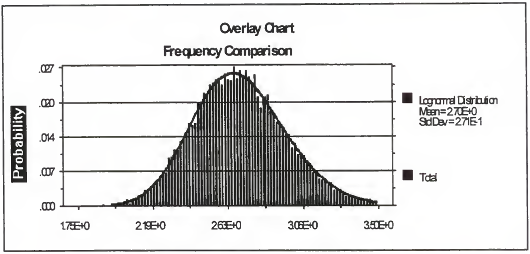
Set 7
Crystal Ball Output
Distributions Fitting Chart

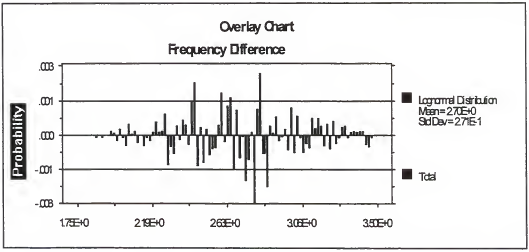




Grocery Store Data
Ra-226

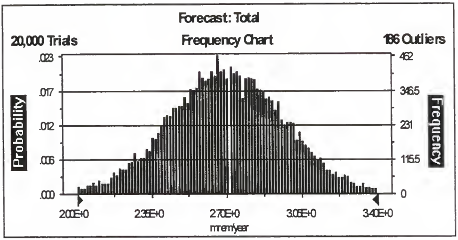
Set 7
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Ra-226

Set 8
Crystal Ball Output
Frequency Chart

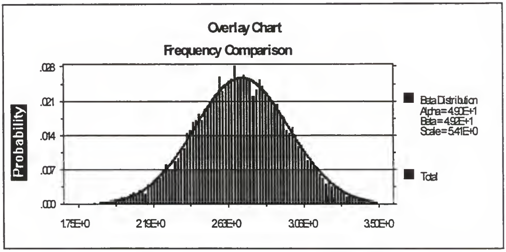


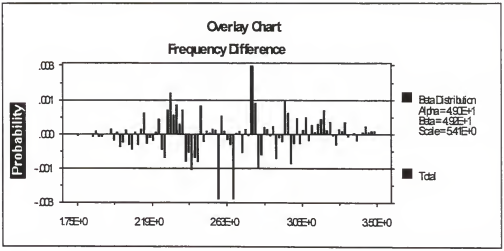
Forecast: Total

Statistic	Value
Trials	20000
Mean	2.70E+00
Median	2.70E+00
Mode	---
Standard Deviation	2.72E-01
Variance	7.38E-02
Skewness	-0.01
Kurtosis	3.02
Coeff. of Variability	0.1
Range Minimum	1.70E+00
Range Maximum	3.79E+00
Range Width	2.09E+00
Mean Std. Error	1.92E-03

Grocery Store Data
Ra-226

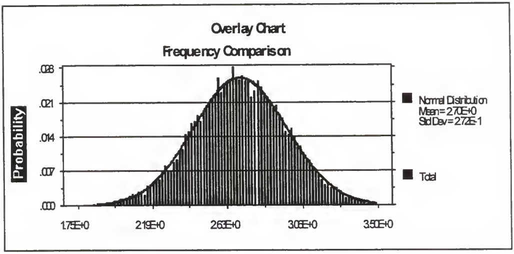
Set 8
Crystal Ball Output
Distributions Fitting Chart

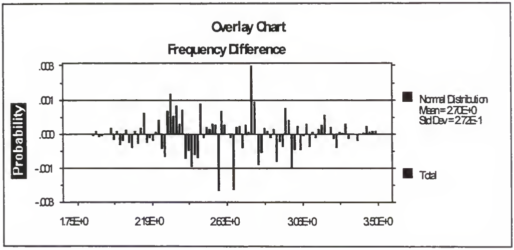




Grocery Store Data
Ra-226

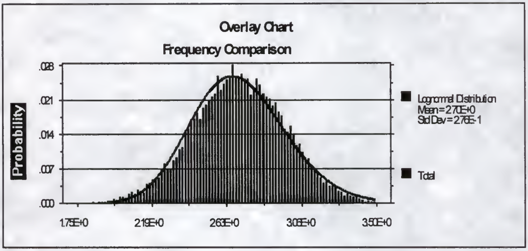
Set 8
Crystal Ball Output
Distributions Fitting Chart

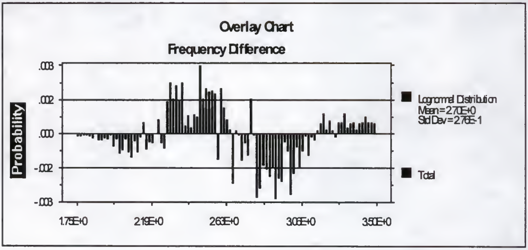




Grocery Store Data
Ra-226

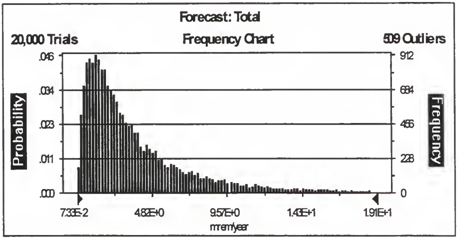
Set 8
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Ra-226

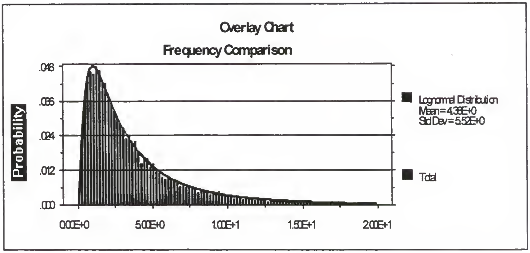
Set 9
Crystal Ball Output
Frequency Chart

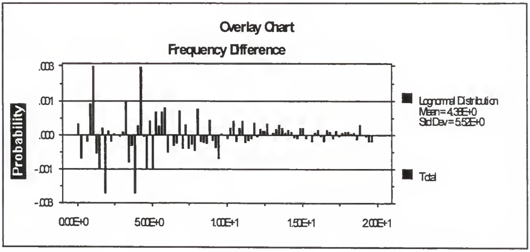


Forecast: Total	
Statistic	Value
Trials	20000
Mean	4.39E+00
Median	2.71E+00
Mode	---
Standard Deviation	5.62E+00
Variance	3.16E+01
Skewness	5.6
Kurtosis	69.91
Coeff. of Variability	1.28
Range Minimum	7.33E-02
Range Maximum	1.50E+02
Range Width	1.50E+02
Mean Std. Error	3.98E-02

Grocery Store Data
Ra-226

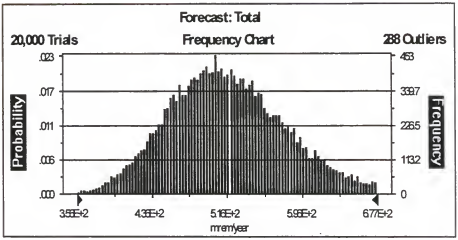
Set 9
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Pb-210

Set 1
Crystal Ball Output
Frequency Chart

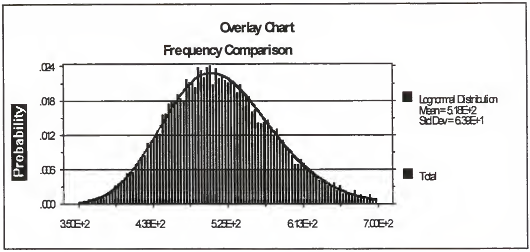


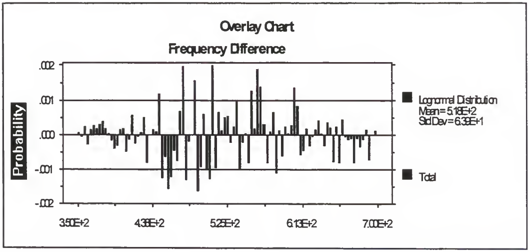
Forecast: Total

Statistic	Value
Trials	20000
Mean	5.18E+02
Median	5.14E+02
Mode	---
Standard Deviation	6.41E+01
Variance	4.10E+03
Skewness	0.41
Kurtosis	3.26
Coeff. of Variability	0.12
Range Minimum	3.09E+02
Range Maximum	8.72E+02
Range Width	5.63E+02
Mean Std. Error	4.53E-01

Grocery Store Data
Pb-210

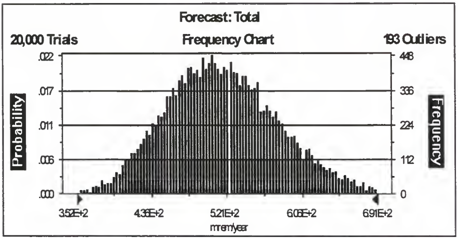
Set 1
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Pb-210

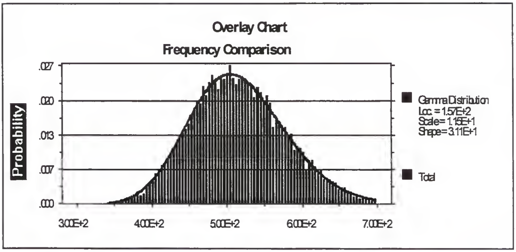
Set 2
Crystal Ball Output
Frequency Chart

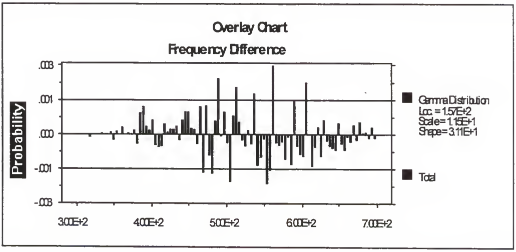


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		5.18E+02
Median		5.14E+02
Mode	---	
Standard Deviation		6.46E+01
Variance		4.18E+03
Skewness		0.36
Kurtosis		3.19
Coeff. of Variability		0.12
Range Minimum		3.13E+02
Range Maximum		8.43E+02
Range Width		5.29E+02
Mean Std. Error		4.57E-01

Grocery Store Data
Pb-210

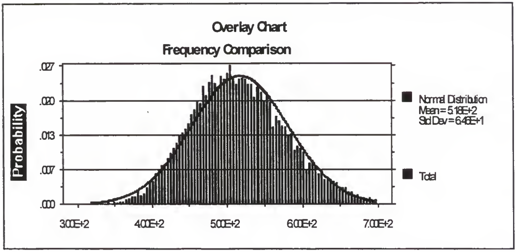
Set 2
Crystal Ball Output
Distributions Fitting Chart

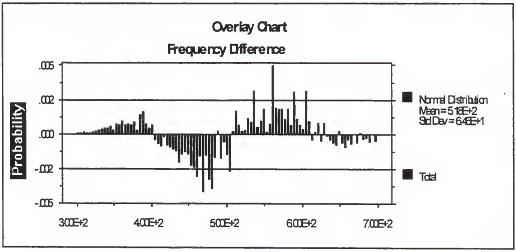




Grocery Store Data
Pb-210

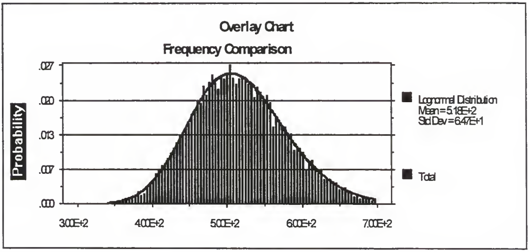
Set 2
Crystal Ball Output
Distributions Fitting Chart

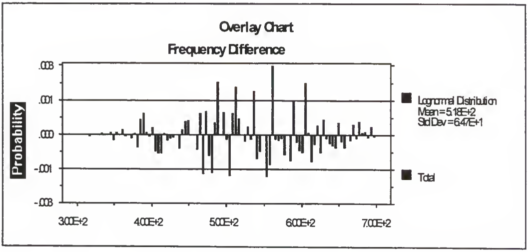




Grocery Store Data
Pb-210

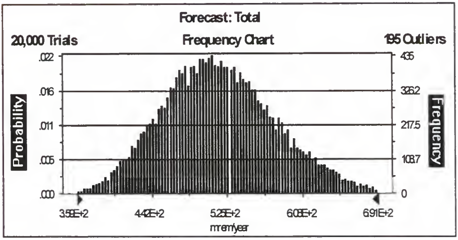
Set 2
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Pb-210

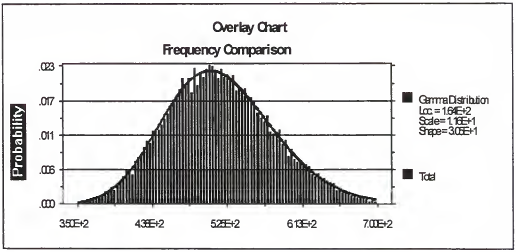
Set 3
Crystal Ball Output
Frequency Chart

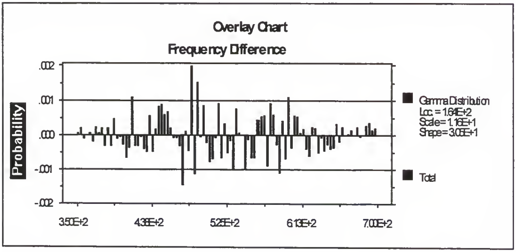


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		5.18E+02
Median		5.14E+02
Mode	---	
Standard Deviation		6.42E+01
Variance		4.13E+03
Skewness		0.37
Kurtosis		3.23
Coeff. of Variability		0.12
Range Minimum		3.12E+02
Range Maximum		8.53E+02
Range Width		5.41E+02
Mean Std. Error		4.54E-01

Grocery Store Data
Pb-210

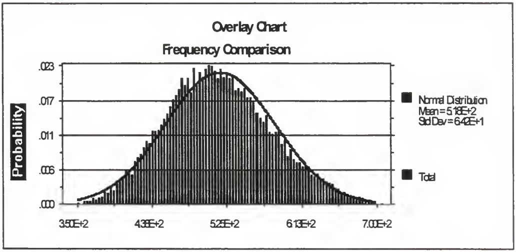
Set 3
Crystal Ball Output
Distributions Fitting Chart

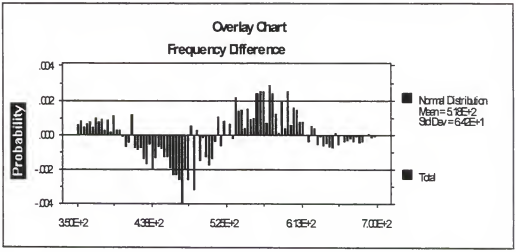




Grocery Store Data
Pb-210

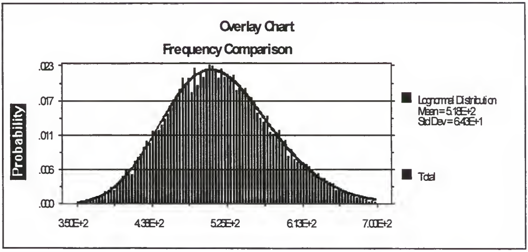
Set 3
Crystal Ball Output
Distributions Fitting Chart

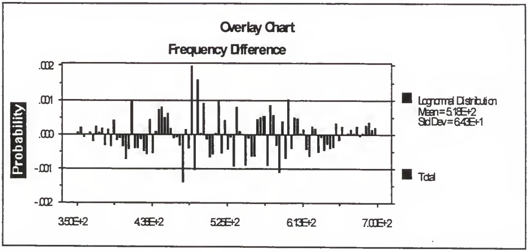




Grocery Store Data
Pb-210

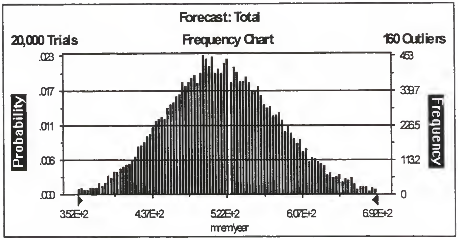
Set 3
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Pb-210

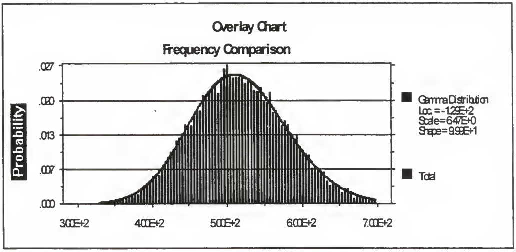
Set 4
Crystal Ball Output
Frequency Chart

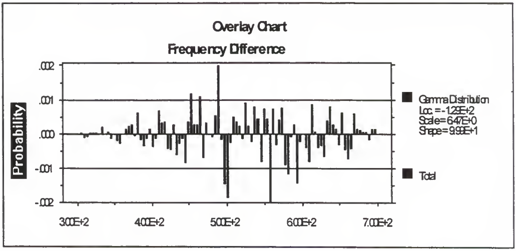


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		5.18E+02
Median		5.16E+02
Mode	---	
Standard Deviation		6.47E+01
Variance		4.18E+03
Skewness		0.2
Kurtosis		3.08
Coeff. of Variability		0.12
Range Minimum		2.82E+02
Range Maximum		8.70E+02
Range Width		5.88E+02
Mean Std. Error		4.57E-01

Grocery Store Data
Pb-210

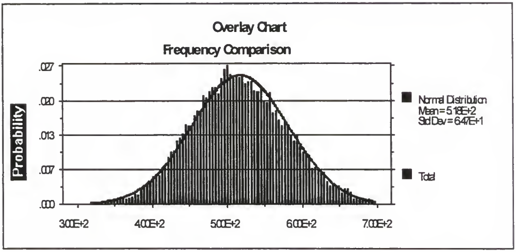
Set 4
Crystal Ball Output
Distributions Fitting Chart

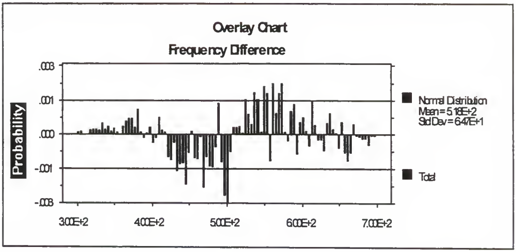




Grocery Store Data
Pb-210

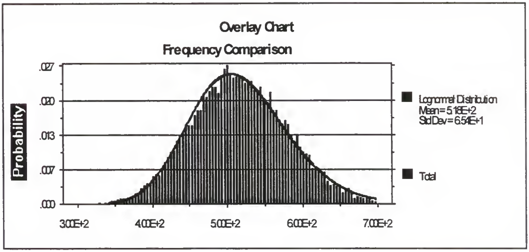
Set 4
Crystal Ball Output
Distributions Fitting Chart

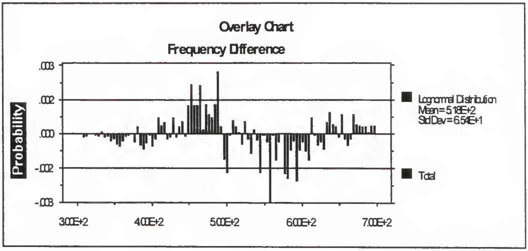




Grocery Store Data
Pb-210

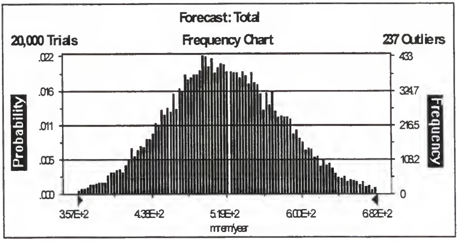
Set 4
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Pb-210

Set 5
Crystal Ball Output
Frequency Chart

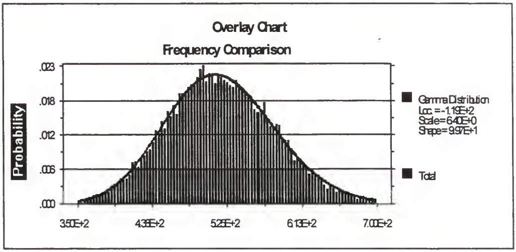


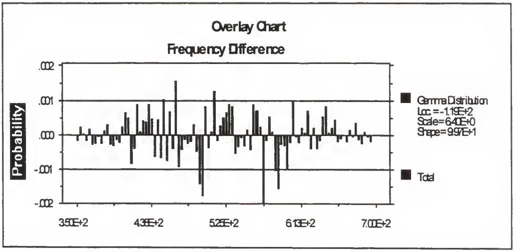
Forecast: Total

Statistic	Value
Trials	20000
Mean	5.18E+02
Median	5.16E+02
Mode	---
Standard Deviation	6.39E+01
Variance	4.09E+03
Skewness	0.21
Kurtosis	3.12
Coeff. of Variability	0.12
Range Minimum	3.02E+02
Range Maximum	8.43E+02
Range Width	5.41E+02
Mean Std. Error	4.52E-01

Grocery Store Data
Pb-210

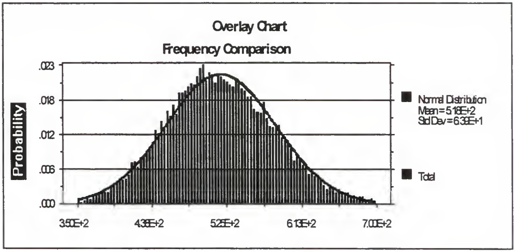
Set 5
Crystal Ball Output
Distributions Fitting Chart

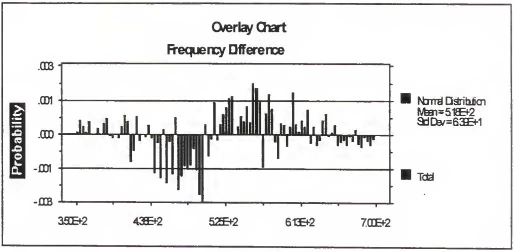




Grocery Store Data
Pb-210

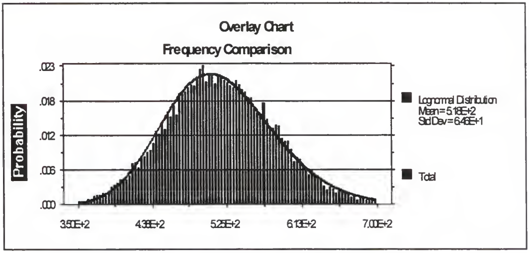
Set 5
Crystal Ball Output
Distributions Fitting Chart

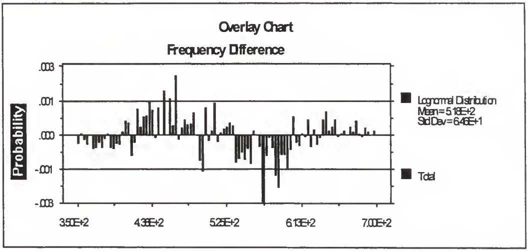




Grocery Store Data
Pb-210

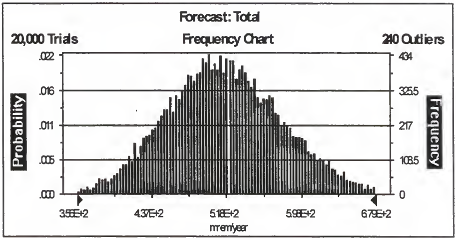
Set 5
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Pb-210

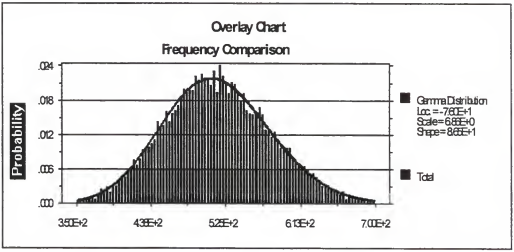
Set 6
Crystal Ball Output
Frequency Chart

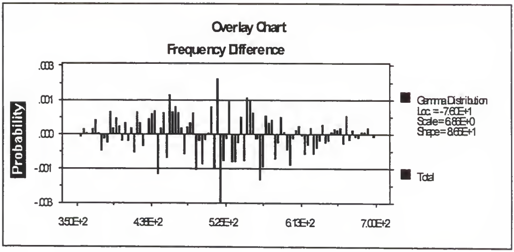


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		5.17E+02
Median		5.14E+02
Mode	---	
Standard Deviation		6.38E+01
Variance		4.07E+03
Skewness		0.22
Kurtosis		3.14
Coeff. of Variability		0.12
Range Minimum		2.69E+02
Range Maximum		8.45E+02
Range Width		5.76E+02
Mean Std. Error		4.51E-01

Grocery Store Data
Pb-210

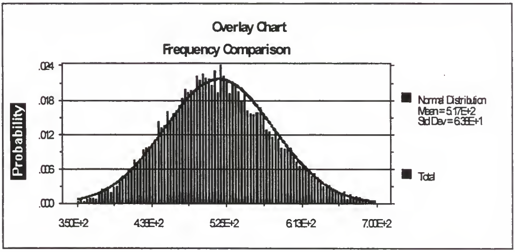
Set 6
Crystal Ball Output
Distributions Fitting Chart

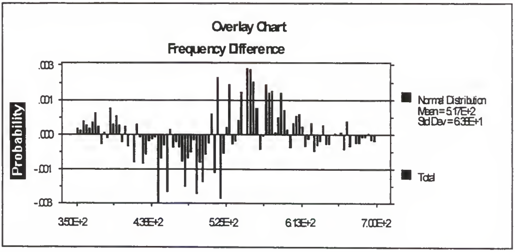




Grocery Store Data
Pb-210

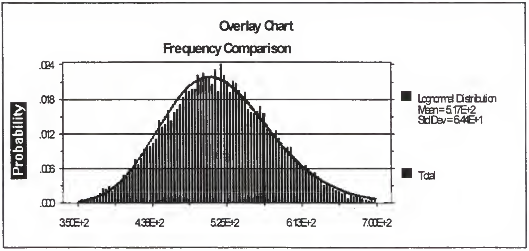
Set 6
Crystal Ball Output
Distributions Fitting Chart

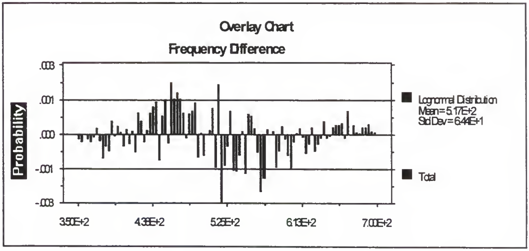




Grocery Store Data
Pb-210

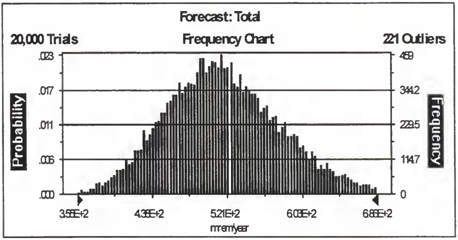
Set 6
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Pb-210

Set 7
Crystal Ball Output
Frequency Chart

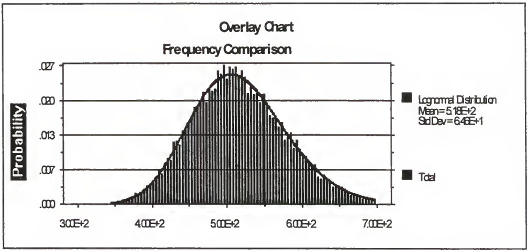


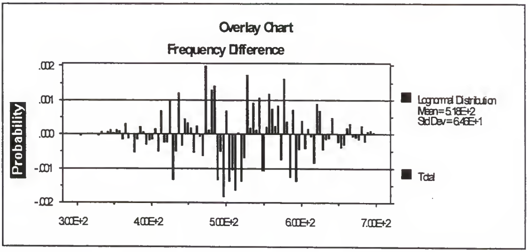
Forecast: Total

Statistic	Value
Trials	20000
Mean	5.18E+02
Median	5.14E+02
Mode	---
Standard Deviation	6.47E+01
Variance	4.18E+03
Skewness	0.39
Kurtosis	3.26
Coeff. of Variability	0.12
Range Minimum	3.04E+02
Range Maximum	8.33E+02
Range Width	5.29E+02
Mean Std. Error	4.57E-01

Grocery Store Data
Pb-210

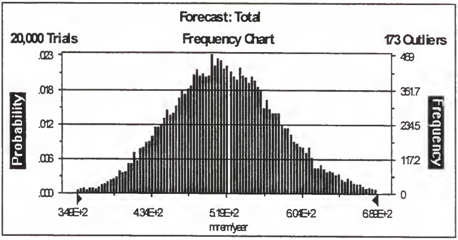
Set 7
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Pb-210

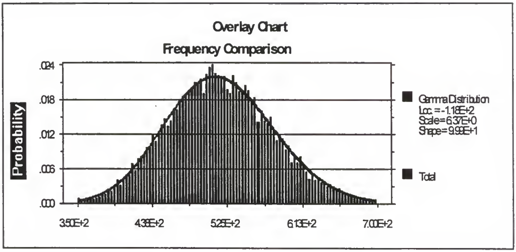
Set 8
Crystal Ball Output
Frequency Chart

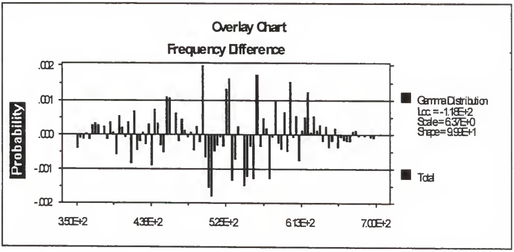


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		5.18E+02
Median		5.16E+02
Mode	---	
Standard Deviation		6.37E+01
Variance		4.06E+03
Skewness		0.21
Kurtosis		3.16
Coeff. of Variability		0.12
Range Minimum		2.75E+02
Range Maximum		8.04E+02
Range Width		5.29E+02
Mean Std. Error		4.50E-01

Grocery Store Data
Pb-210

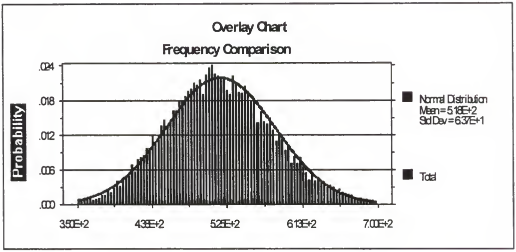
Set 8
Crystal Ball Output
Distributions Fitting Chart

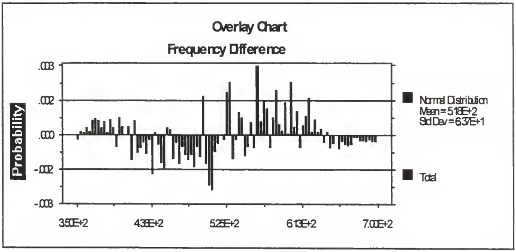




Grocery Store Data
Pb-210

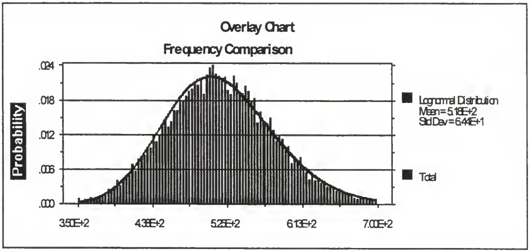
Set 8
Crystal Ball Output
Distributions Fitting Chart

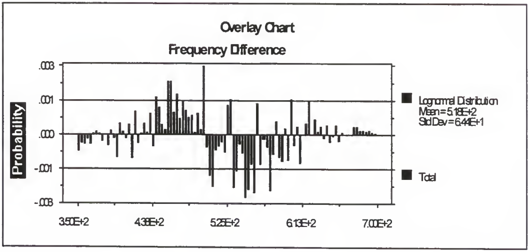




Grocery Store Data
Pb-210

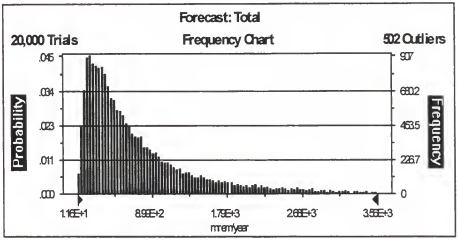
Set 8
Crystal Ball Output
Distributions Fitting Chart





Grocery Store Data
Pb-210

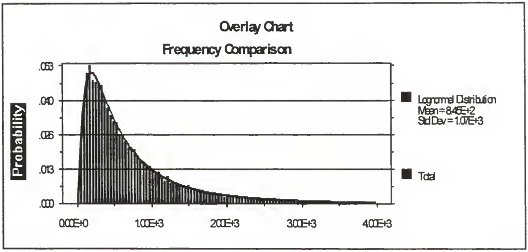
Set 9
Crystal Ball Output
Frequency Chart

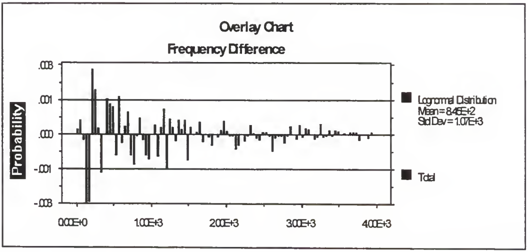


Forecast: Total		
Statistic	Value	
Trials		20000
Mean		8.44E+02
Median		5.25E+02
Mode	---	
Standard Deviation		1.08E+03
Variance		1.16E+06
Skewness		6.02
Kurtosis		86.32
Coeff. of Variability		1.27
Range Minimum		1.00E+01
Range Maximum		3.15E+04
Range Width		3.15E+04
Mean Std. Error		7.61E+00

Grocery Store Data
Pb-210

Set 9
Crystal Ball Output
Distributions Fitting Chart





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BIOGRAPHICAL SKETCH

Ward L. Dougherty was born in Stamford, Connecticut, on February 27, 1963. He was raised in Lutz, Florida. He joined the Navy in December 1986. He met and married his wife, Gwendolyn Bennett, while in the Navy on August 18, 1990. His son, Justin, was born while he was stationed in Charleston, South Carolina, on August 24, 1991. His daughter, Michelle, was born just prior to completing his Naval service on February 5, 1993. He served on board two submarines, the U.S.S. James Madison (SSBN 627) and the U.S.S. Dolphin (AGSS 555). He achieved the engineering watch supervisor and engineering duty petty office qualification while on board the Madison. As an E-5 he was one of only two people to ever qualify, in the 30-year history of the boat, to that watchstation at his rank. His awards include Humanitarian, Good Conduct (2), Sea Service Ribbon, National Defense Service Medal, and the Submarine Qualification with four patrol pins. He completed over six years with ah honorable discharge in March 1993.

He attended the University of Florida, College of Engineering, Department of Nuclear and Radiological Engineering, from April 1993 until May 1999. He worked for Innovative Nuclear Space Power and Propulsion Institute from 1996-1999 and has attended numerous space nuclear power conferences. He graduated from nuclear engineering with a bachelor's degree with high honors in August 1996 and with a master's degree in December 1999. He transferred to environmental engineering and subsequently

dual enrolled in nuclear and environmental to pursue concurrent Ph.D. degrees in nuclear engineering and environmental engineering.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

W. Emmett Bolch

W. Emmett Bolch, Jr., Chair
Professor of Environmental Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Wesley E. Bolch

Wesley E. Bolch
Associate Professor of Nuclear and Radiological Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

William S. Properzio
Associate Professor of Environmental Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

G. Ronald Dalton

G. Ronald Dalton
Professor of Nuclear and Radiological Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Angela S. Lindner
Assistant Professor of Environmental Engineering Sciences

This dissertation was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

May 2001

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Dean, Graduate School